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HYPERSONIC AERODYNAMIC CHARACTERISTICS OF A MODEL OF A LOW-FINENESS-RATIO VARIABLE-GEOMETRY LOGISTICS SPACECRAFT CONCEPT

by Bernard Spencer, Jr.

Langley Research Center
Langley Station, Hampton, Va.

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SUMMARY

An investigation has been made in the Langley 15-inch hypersonic flow apparatus at a Mach number of 10.03 to determine the static aerodynamic characteristics of a model of a low-fineness-ratio variable-geometry logistics spacecraft concept designed for hypersonic lift-drag ratios near 1.0. The variable-geometry feature envisioned for the configuration is a fold-down-type wing, stowed in the triangular side areas of the body during entry and deployed at subsonic speeds for improvement in subsonic performance. The variable-geometry feature is considered to be retracted for the present hypersonic tests.

Addition of outboard tails having either 60° or 50° leading-edge sweep at 0° dihedral to the body—vertical-tail configuration increased maximum lift-drag ratio and provided both longitudinal and directional stability throughout the test angle-of-attack range. Incrementally increasing dihedral angle from 0° to 45° with elevon controls at 0° provided a trim angle-of-attack range from 21.5° to 32° and 21° to 29.8° for the tails having 60° or 50° leading-edge sweep, respectively. Deflection of the elevon controls for either tail at a constant dihedral of either 15° or 30° indicated a larger range of trimmable angle of attack, the largest trim change being noted for the elevons-down configurations. Positive effective dihedral occurred for all configurations, a reduction in positive effective dihedral occurring above 30° outboard tail dihedral for either tail configuration, especially at the higher angles of attack.

INTRODUCTION

The National Aeronautics and Space Administration is presently studying the application of variable-geometry wings for improving subsonic aerodynamic performance on lifting-entry spacecraft concepts envisioned as possible manned logistics vehicles, the present spectrum of concepts encompassing hypersonic lift-drag ratio levels near 1.0, 2.0, and 3.0. The variable-geometry features added to each configuration have been designed to allow retention of efficient hypersonic shaping uncompromised for off-design requirements such as horizontal land landing capability. The purpose of the present paper is to present results obtained at hypersonic speeds on one such configuration, designed for hypersonic lift-drag ratio near 1 and employing as a variable-geometry feature, a fold-down-type wing stowed in the triangular side areas of the body during entry and deployed at subsonic speeds to improve subsonic and landing aerodynamic characteristics. For the present hypersonic tests, this feature described is considered to be retracted.

The configuration investigated in the present test consisted of a blunt-nose body having modified triangular cross section with elliptic lower surface, a large blunt base, and suitable stabilizing surfaces. Outboard tails, located near the base of the model were tested for leading-edge-sweep angles of 50° and 60° at dihedral angles of 0°, 15°, 30°, 45°, and 60°. Elevon controls located at the trailing edge of the tails were tested for pitch control at deflections of 20°, 0°, -10°, and -20° for several tail dihedral positions and were differentially deflected for roll-yaw control. A single center-line vertical tail was also incorporated on the model for directional stability. Tests were made in the Langley 15-inch hypersonic flow apparatus at a Mach number of 10.03, and a corresponding Reynolds number (based on model length) of 1.25×10^{6}. Angle-of-attack range for the investigation was from approximately 0° to 34° at angles of sideslip of 0° and -6°.

SYMBOLS

Longitudinal aerodynamic characteristics are presented about the stability axis; lateral-directional results are presented about the body axis. All coefficients have been normalized with respect to actual body length, projected planform area, and maximum body span (excluding tails). The moment reference point has been selected at 52 percent of the actual body length aft of the body apex, and 6.30 percent of the actual body length below the model horizontal reference plane. (See fig. 1.)

b body span at base, 4.50 inches (11.43 centimeters)

C_D drag coefficient, $\frac{\text{Drag}}{qS}$

C_L lift coefficient, $\frac{\text{Lift}}{qS}$

C_l rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSb}$

C_{l_β} lateral-stability parameter, $\frac{\Delta C_l}{\Delta \beta}$; $\beta = 0^{\circ}, -6^{\circ}$

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{qSl}$

C_n yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb}$

C_{n_β} directional-stability parameter, $\frac{\Delta C_n}{\Delta \beta}$; $\beta = 0^o, -6^o$

C_Y side-force coefficient, $\frac{\text{Side force}}{qS}$

C_{Y_β} side-force parameter, $\frac{\Delta C_Y}{\Delta \beta}$; $\beta = 0^o, -6^o$

L/D lift-drag ratio

l actual body length, 9.61 inches (24.41 centimeters)

l' theoretical body length, 10.00 inches (25.40 centimeters)

q dynamic pressure, pounds/square foot (newtons/meter^2)

r radius, inches (centimeters)

S reference area, body projected-planform area, 0.2066 square foot (0.01918 meter^2)

y_1 vertical distance from body reference line to lower surface of body at station x, feet (meters)

y_2 semi-minor axis of elliptic lower surface of body, feet (meters)

z semi-major axis of elliptic lower surface of body, feet (meters)

α angle of attack, measured from body horizontal reference plane, degrees

β angle of sideslip, degrees

Γ_t outboard-tail dihedral angle (positive with tip chord up), degrees

δ_e elevon-control deflection (positive with trailing edge down), degrees

Λ_t outboard-tail leading-edge-sweep angle, degrees

x longitudinal ordinate of body as measured from theoretical apex, feet (meters)

Subscripts:

l left

r right

max maximum condition

min minimum condition

trim trimmed condition

Configuration designations:

B body alone

V vertical tail

H_1 outboard tails with 60° sweep

H_2 outboard tails with 50° sweep

MODEL

The lifting-body design represents an attempt to provide a configuration having hypersonic lift-drag ratio near 1.0, maximum volume for crew and payload, minimum wetted area, and an attendant minimal structural weight. Drawings of the basic body, the two outboard tail planforms including elevons, and the vertical tail are shown in figure 1 with a photograph of configuration BH_1V presented as figure 2.

The body, which was designed with a blunt nose and modified triangular cross section, has an equivalent fineness ratio of approximately 3.0. A canopy section is located forward on the body to afford good pilot visibility during low-speed approach and landing. The lower surface of the body is elliptic, with major to minor axis ratio of 3. The sides of the body are canted inward 30° from the vertical, the upper surface being modified from the triangular shape by a radius employed to minimize unusable volume. Design ordinates for the body are presented in table I.

Outboard tails having leading-edge sweep angles of 60° and 50° were tested at dihedral angles of 0°, 15°, 30°, 45°, and 60°. These tails were flat plate in section, 0.100 inch (0.254 cm) thick with leading-edge radius of 0.050 inch (0.127 cm) measured normal to the leading edge. The ratio of total exposed outboard-tail area to reference area was 0.14. This area included the elevon controls which were located on the tails so that the hinge line corresponded to the most aft body station. Control deflections of 20°, 0°, -10°, and -20° were tested with differential deflections for roll control. The center-line vertical tail had a flat-plate section 0.100 inch (0.254 cm) thick with 45° leading-edge sweep and 0.050 inch (0.127 cm) leading-edge radius as measured normal to the leading edge. The ratio of exposed vertical-tail area to reference area was 0.062.

TESTS AND CORRECTIONS

The present investigation was made in the Langley 15-inch hypersonic flow apparatus at a Mach number of 10.03. A brief description of this facility is given in reference 1. Tests were made at a stagnation temperature of approximately 1150° F (621° C) and a stagnation pressure of 900 lb/sq in. (6205 kN/m^2) corresponding to a Reynolds number, based on body length of 1.25×10^6. No attempt was made to fix transition in these tests.

Forces and moments were measured with a sting-supported six-component water-cooled strain-gage balance. The angle-of-attack range of the investigation was from approximately 0° to 34° at sideslip angles of 0° and -6°. Lateral directional derivatives C_{Y_β}, C_{n_β}, and C_{l_β} were calculated from increments obtained between angles of sideslip of 0° and -6° and therefore do not account for any nonlinearities which may exist in the intermediate sideslip range.

Angle of attack and angle of sideslip have been corrected for the effects of sting and balance deflection under load. The drag data represent gross drag in that the effect of base pressure is included in the measured drag values.

PRESENTATION OF RESULTS

Basic longitudinal aerodynamic characteristics obtained for the body and various combinations of model components are presented in figure 3. The effects of outboard-tail dihedral are presented in figures 4 and 5 for the tail having 60° and 50° leading-edge sweep, respectively. The effects of elevon pitch-control deflection on the longitudinal-control characteristics for the two outboard-tail configurations at dihedral angles of 15° and 30° are presented in figures 6 and 7, and elevon roll-control characteristics for these configurations are presented in figure 8. Trimmed longitudinal characteristics for elevon controls at various fixed dihedral angles and the effects of variable outboard-tail dihedral for fixed elevons at 0° are presented in figure 9 for tails with both 50° and 60° leading-edge sweep. A summary of the lateral-directional-stability characteristics for the body and various combinations of model components are presented in figure 10, the effects of tail dihedral being presented in figure 11 for the tails with both 60° and 50° leading-edge sweep.

DISCUSSION

Longitudinal Characteristics

The addition of the outboard tails to the BV configuration (fig. 3) resulted in a stable configuration throughout the angle-of-attack range, with accompanying increases in lift-curve slope and minimum drag ($\Lambda_t = 60^{\circ}$ or 50°). Small increases in $(L/D)_{max}$ (1.36 to 1.43 for H_1 and 1.36 to 1.39 for H_2) were also noted; thus, the desirability of adding stabilizing or lifting surfaces to this low hypersonic lift-drag configuration was indicated. Trends observed in other studies of higher performance lifting bodies as affected by the addition of similar stabilizing surfaces, however, have indicated considerable loss in maximum lift-drag ratio. (See ref. 2.)

Increasing tail dihedral ($\Lambda_t = 60^{\circ}$ or 50°) from 0° to 45° resulted in a trim angle-of-attack range from approximately 21.5° to 32° and 21° to 29.8°, respectively (see figs. 4, 5, or 9), with the moment reference point at 52-percent body length; thus, a rather wide range of trimmable angle of attack will be afforded by use of variable dihedral tails.

Results of tests using the elevon controls for either outboard tail (H_1 or H_2) at dihedral angles of 15° or 30° similarly indicate a wide range of trimmed angle of attack, the largest change in trim occurring for $\delta_e = 20^{\circ}$ (that is, elevon-down configuration). (See fig. 6, 7, or 9.)

Data for the outboard tail with 60° sweep, using combined elevon and dihedral deflection, show trimmed angle of attack from 10.8° for $\Gamma_t = 15^{\circ}$ to 30.8° for $\Gamma_t = 30^{\circ}$ with trimmed $(L/D)_{max}$ of approximately 1.4 occurring near $\alpha = 16^{\circ}$ to $\alpha = 18^{\circ}$. The data for the outboard tail with 50° sweep, using combined elevon and dihedral deflection show trimmed angle of attack from 8.6° for $\Gamma_t = 15^{\circ}$ to 30.2° for $\Gamma_t = 30^{\circ}$ with trimmed $(L/D)_{max}$ of approximately 1.38 near $\alpha = 18^{\circ}$ to $\alpha = 20^{\circ}$.

Lateral-Directional-Stability and Control Characteristics

Figure 8 presents roll-control effectiveness characteristics for configurations BH_1V and BH_2V for $\Gamma_t = 15^{\circ}$ or 30° with the elevons differentially deflected. Positive roll control for the configurations having $\Gamma_t = 15^\circ$ (H_1 or H_2) throughout the angle-of-attack range was noted, control reversal ($-C_l$) occurring for configuration BH_1V having $\Gamma_t = 30^\circ$ above an angle of attack of about 16°. Unfavorable yaw ($-C_n$) was noted for all configurations except BH_2V, $\Gamma_t = 15^\circ$ which indicates positive C_n up to $\alpha \approx 18^\circ$ $\left(\alpha \text{ near } (L/D)_{max}\right)$ but considerably below a trim angle of attack of approximately 29.5° (fig. 8).

The body-alone configuration (fig. 10) indicates approximately neutral-directional-stability characteristics throughout the test angle-of-attack range and positive effective dihedral resulting from the contribution of the lateral surfaces of the body. Data derived after addition of the center-line vertical tail indicate large increases in C_{n_β} at low angles of attack with loss in effectiveness accompanying increasing angle of attack as expected, because of the shielding effect. Similarly, the contribution of the vertical tail to C_{l_β} diminishes with increasing angle of attack, and that contribution vanishes above an angle of attack of 18°. The addition of the outboard tails at $\Gamma_t = 0^\circ$ (H_1 or H_2) to the BV configuration results in data that indicate a favorable effect on the lateral center of pressure, with considerable increase in C_{l_β} shown. It is interesting to note an almost constant incremental increase in C_{n_β} resulting from addition of either outboard tail (H_1 or H_2) at $\Gamma_t = 0^\circ$ throughout the angle-of-attack range. The favorable effect of the outboard tail can possibly be attributed to a combination of tail axial force acting favorably on the windward tail and favorable interference. Similar results were noted in reference 2.

Increasing dihedral for the BH_1V configuration (fig. 11(a)) produces progressive increases in C_{n_β} in the angle-of-attack range from approximately 4° to 16°, the highest values of C_{n_β} being noted for $\Gamma_t = 30^\circ$ at the highest angle of attack. Positive effective dihedral occurred for any Γ_t on this configuration, with reductions in $-C_{l_\beta}$ above about 8° as Γ_t becomes greater than 30°, especially at the higher angles of attack. Similar lateral-directional-stability characteristics are noted for the BH_2V configuration, this configuration showing somewhat higher values of C_{n_β} for a given dihedral than that of the corresponding BH_1V configuration. (See fig. 11.)

CONCLUSIONS

An investigation has been made at a Mach number of 10.03 to determine the static aerodynamic characteristics of a model of a low-fineness-ratio variable-geometry logistics spacecraft concept design for hypersonic lift-drag ratios near 1.0. The configuration is a lifting body with a blunt nose, a modified triangular cross section, an elliptic lower surface, and a large blunt base. The effects of the addition of outboard tails, tail leading-edge sweep and dihedral angle, and elevon-control effectiveness on both the longitudinal and lateral directional stability and control have been investigated. Results of the investigation may be summarized as follows:

1. Addition of outboard tails having either 60° or 50° leading-edge sweep at 0° dihedral to the body—vertical-tail configuration increased lift-curve slope and minimum drag, with small resultant increases in maximum lift-drag ratio. Addition of either tail also resulted in longitudinally and directionally stable configurations throughout the angle-of-attack range.

2. Incrementally increasing dihedral angle from 0° to 45° with elevon controls at a deflection angle of 0° provided a trim angle-of-attack range from 21.5° to 32° and 21° to 29.8° for the tails having leading-edge sweep angles of 60° or 50°, respectively.

3. Deflection of the elevon controls for either tail at a constant dihedral angle of either 15° or 30° indicated a larger range of trimmable angle of attack, the largest trim change being noted for the elevons-down configurations.

4. Positive roll control was obtained for the outboard-tail configurations with sweep angles of either 60° or 50° at a dihedral angle of 15° with elevons differentially deflected. For the outboard tail with a sweep angle of 60° at a dihedral angle of 30°, however, control reversal occurred above an angle of attack of about 16°. Unfavorable yaw due to roll control occurred for all configurations except the 50° sweep outboard tail at 15° dihedral; thus, yaw was positive up to an angle of attack of 18°.

5. Positive effective dihedral occurred for all configurations, a reduction in positive effective dihedral occurring above an outboard-tail dihedral angle of 30° for either tail configuration, especially at the higher angles of attack.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., August 14, 1968,
124-07-02-75-23.

REFERENCES

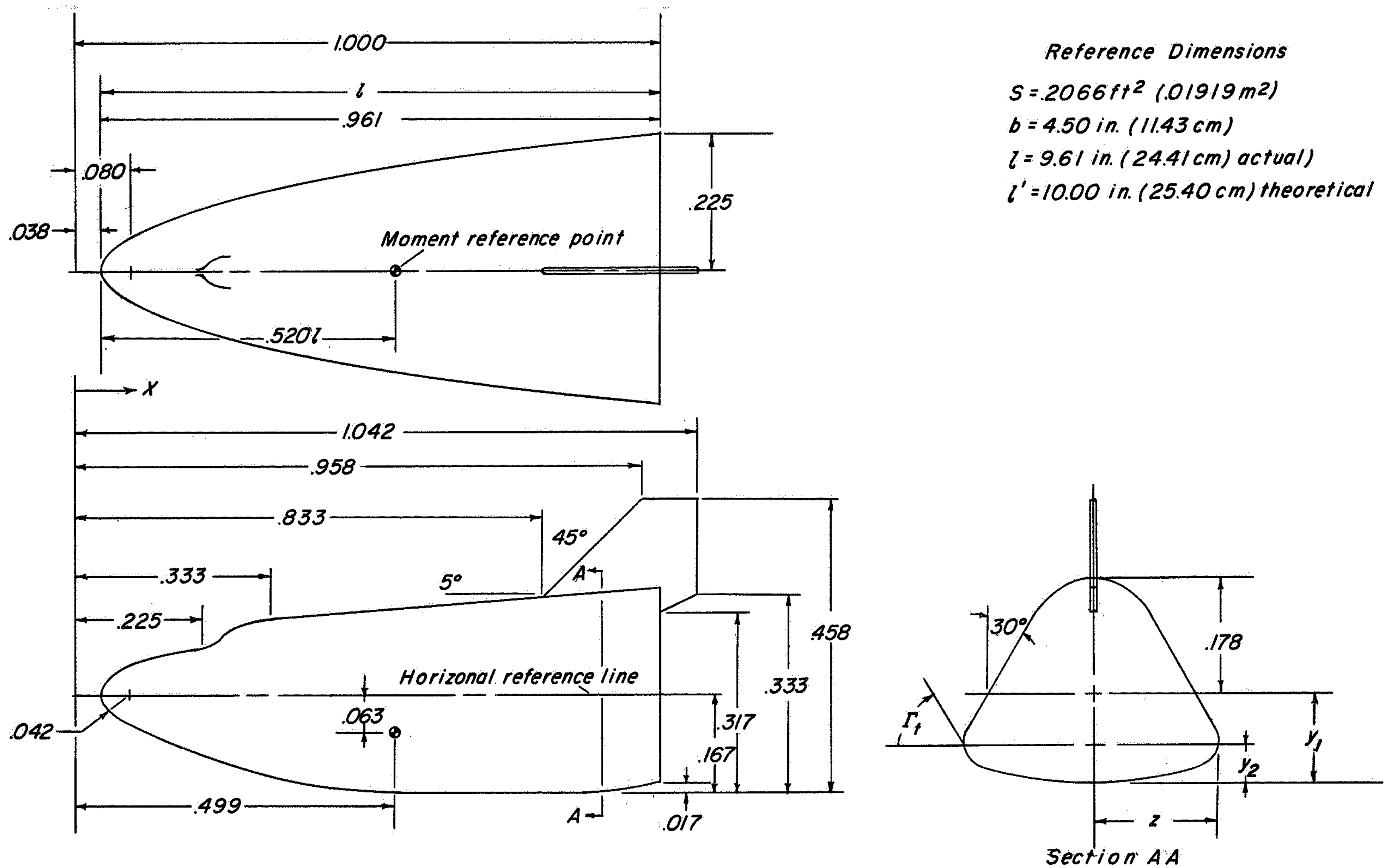
1. Putnam, Lawrence E.; and Brooks, Cuyler W., Jr.: Static Longitudinal Aerodynamic Characteristics at a Mach Number of 10.03 of Low-Aspect-Ratio Wing-Body Configurations Suitable for Reentry. NASA TM X-733, 1962.

2. Fox, Charles H., Jr.; and Spencer, Bernard, Jr.: Hypersonic Aerodynamic Characteristics of Low-Wave-Drag Elliptical-Body—Tail Combinations as Affected by Changes in Stabilizer Configuration. NASA TM X-1620, 1968.

TABLE I.- BODY LOWER SURFACE DESIGN ORDINATES

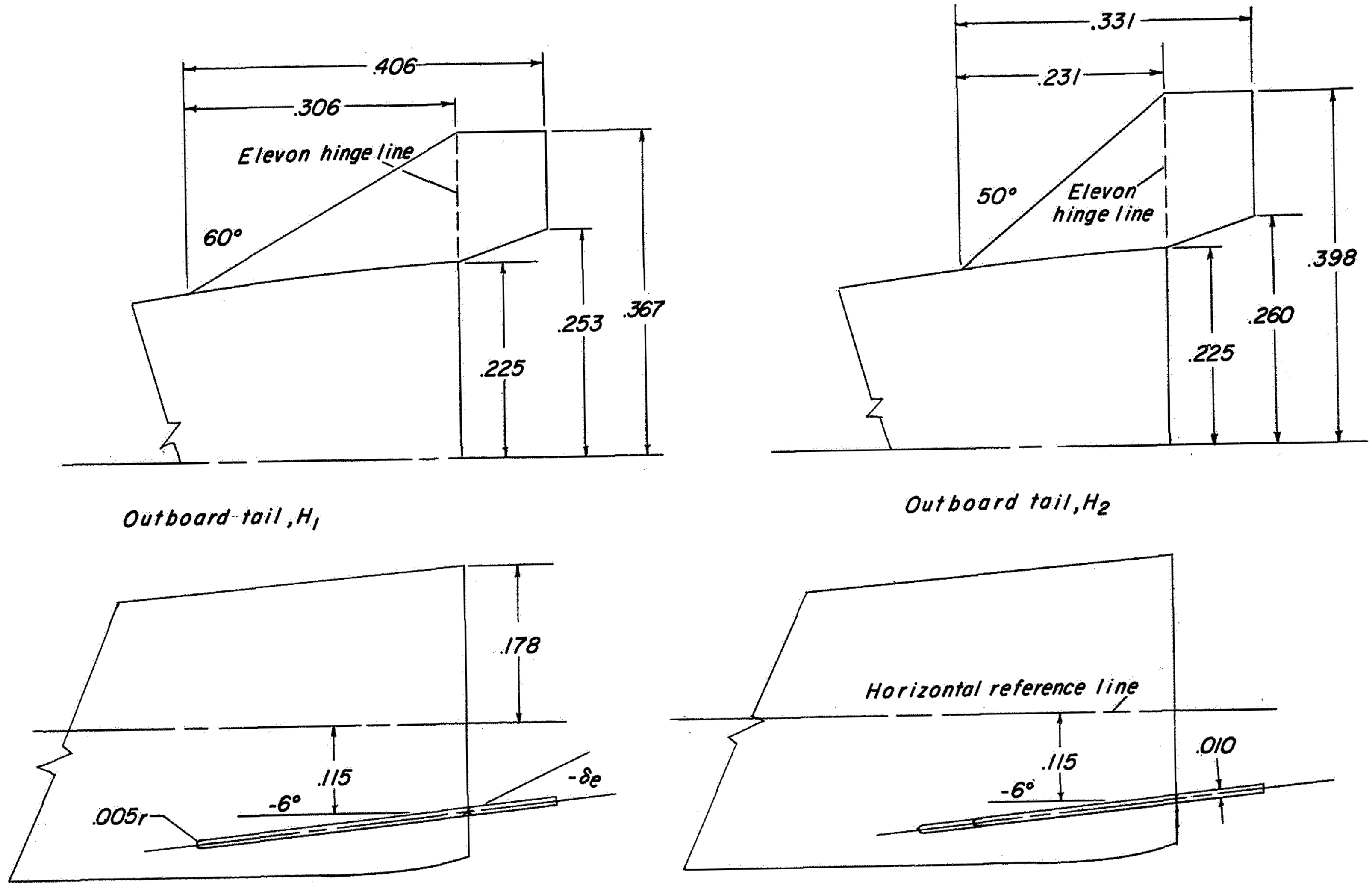
[All dimensions normalized with respect to theoretical length 10.00 in. (25.40 cm)]

x/l	y_1/l	y_2/l	z/l
0	0.000	0.000	0.000
.083	.047	.016	.050
.125	.067	.023	.070
.167	.085	.028	.086
.208	.101	.033	.100
.250	.115	.037	.112
.292	.127	.039	.118
.333	.138	.044	.132
.375	.147	.047	.141
.417	.154	.050	.150
.458	.159	.053	.158
.500	.163	.055	.165
.542	.165	.057	.172
.583	.167	.060	.180
.625	.167	.062	.187
.666	.167	.064	.193
.708	.167	.067	.200
.750	.167	.069	.207
.833	.167	.072	.216
.917	.156	.074	.222
1.000	.150	.075	.225



(a) Basic body with vertical tail.

Figure 1.- Drawings of model and various model components tested. All dimensions based on theoretical body length (10.00 in. (25.40 cm)).



(b) Outboard tails H_1 and H_2.

Figure 1.- Concluded.

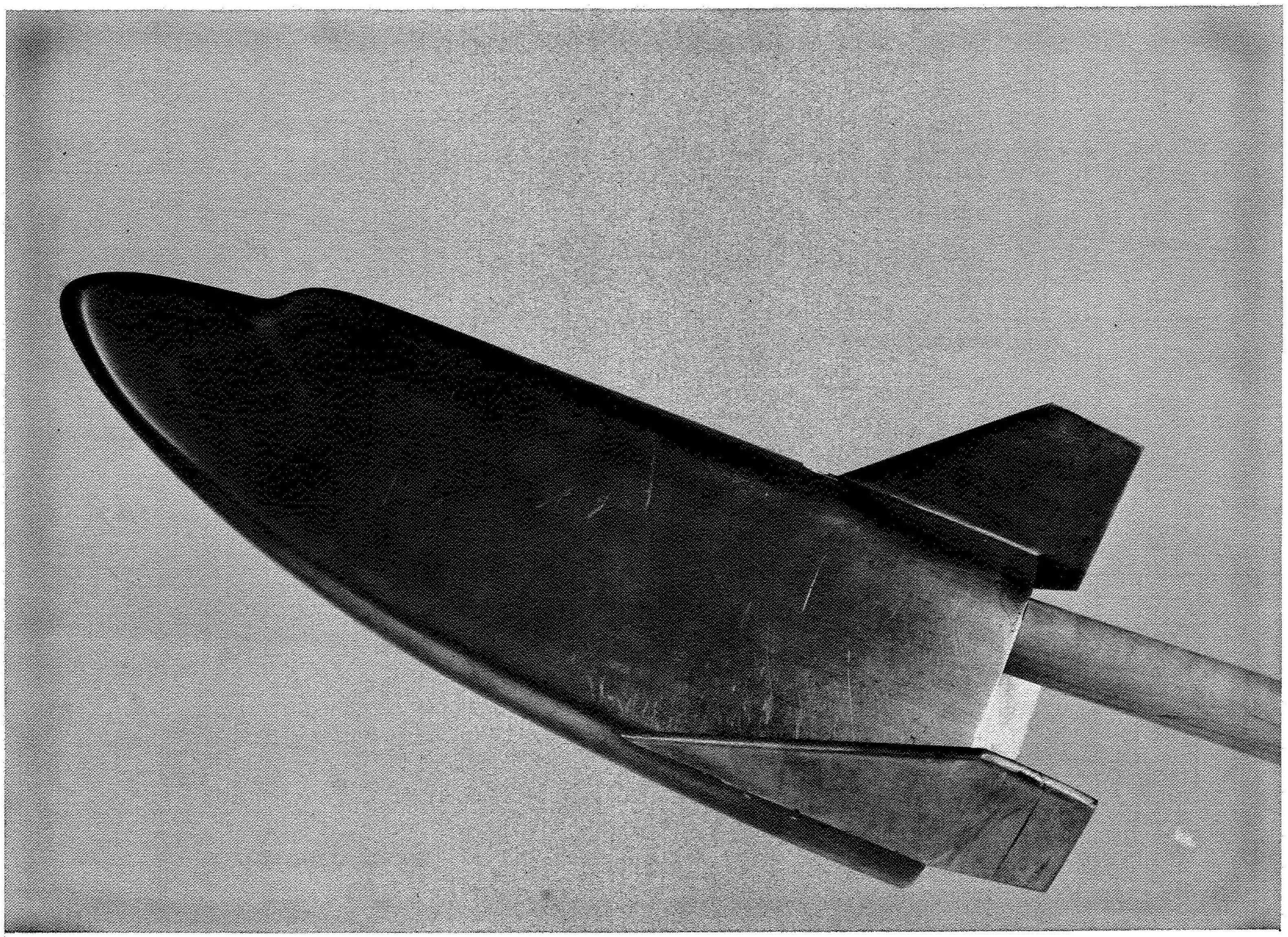


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Figure 2.- Photograph of configuration BH_1V with $\delta_e = 0^o$.

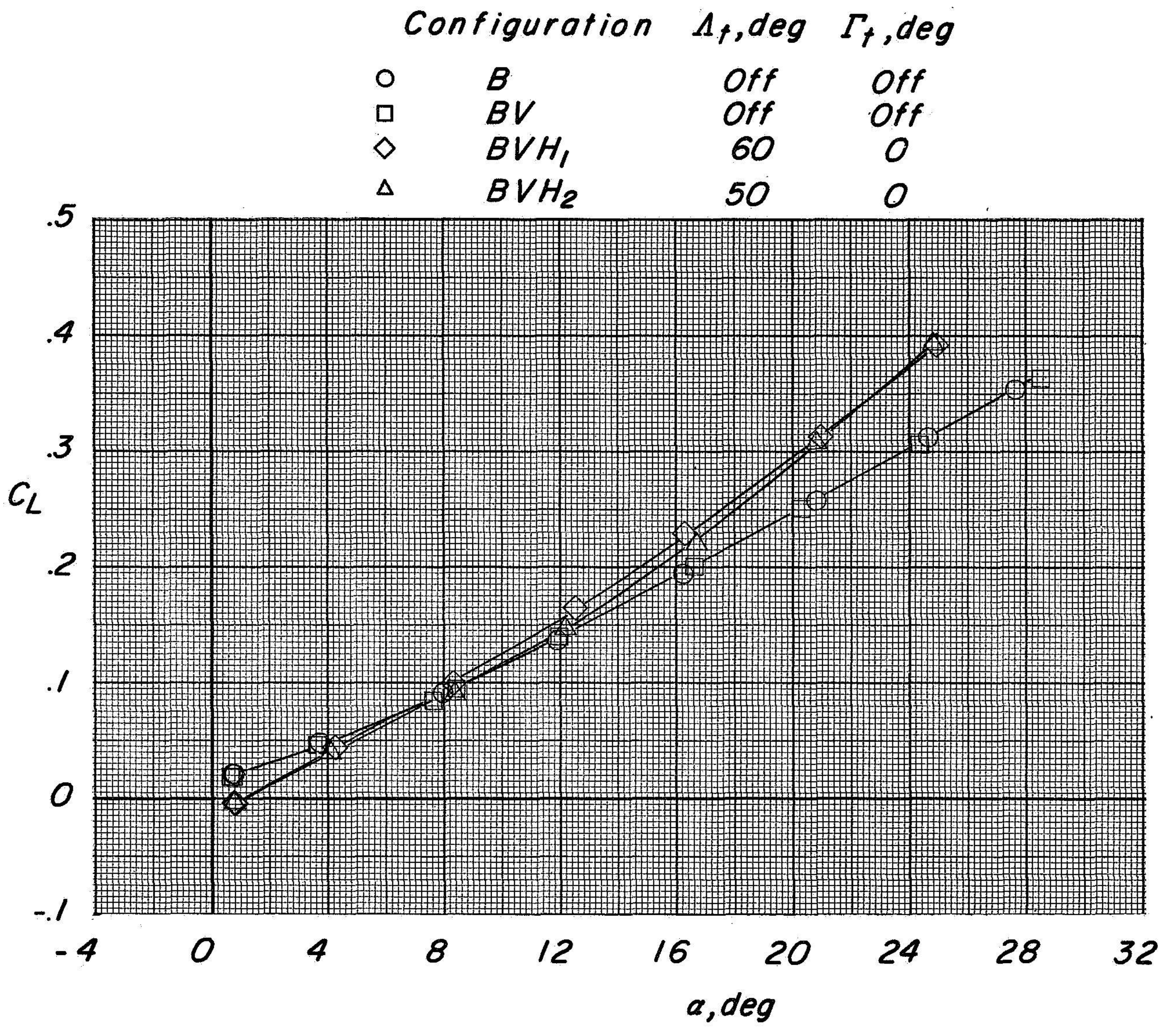


Figure 3.- Longitudinal aerodynamic characteristics of body with various combinations of model components. $\delta_e = 0^0$.

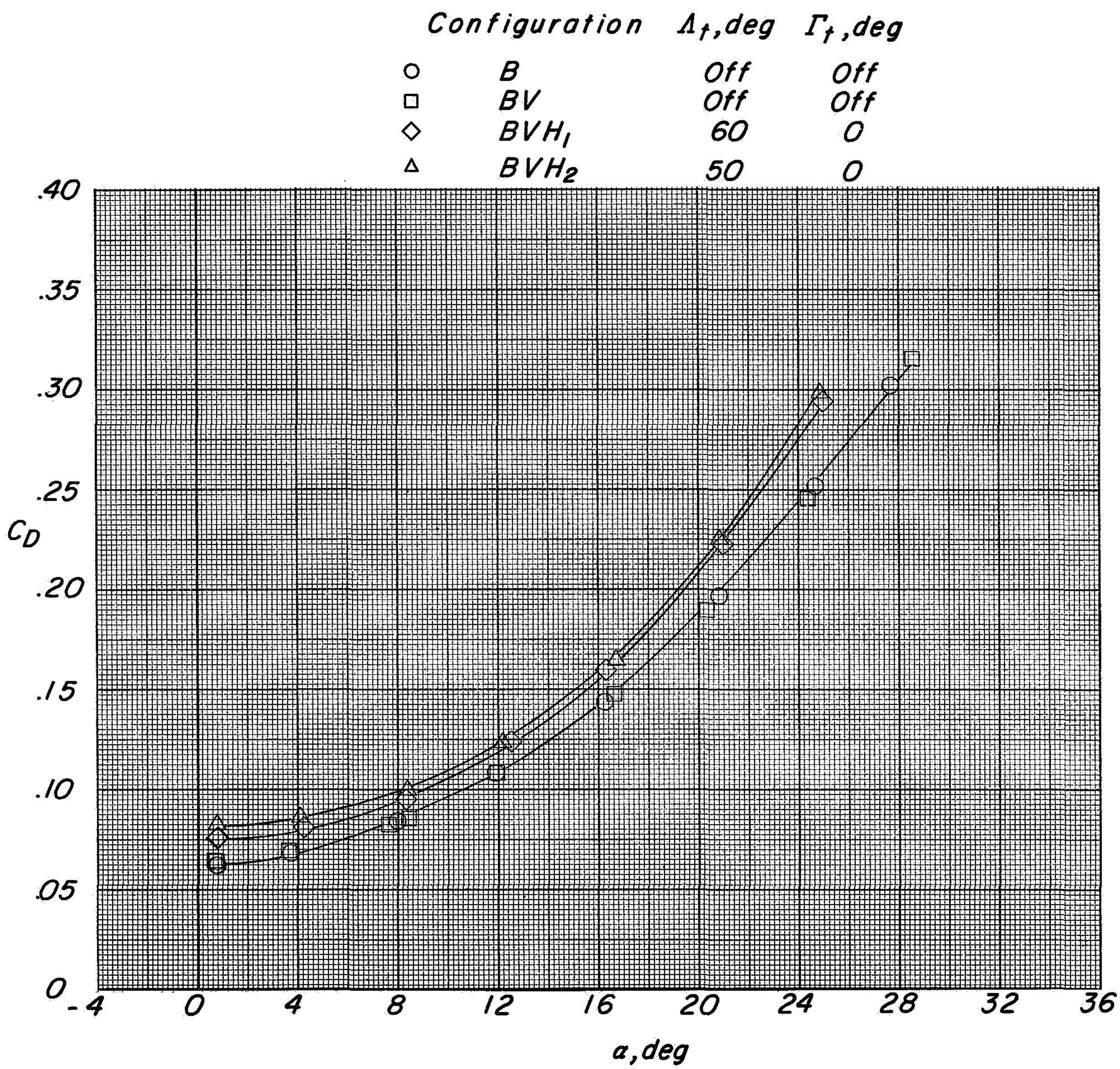
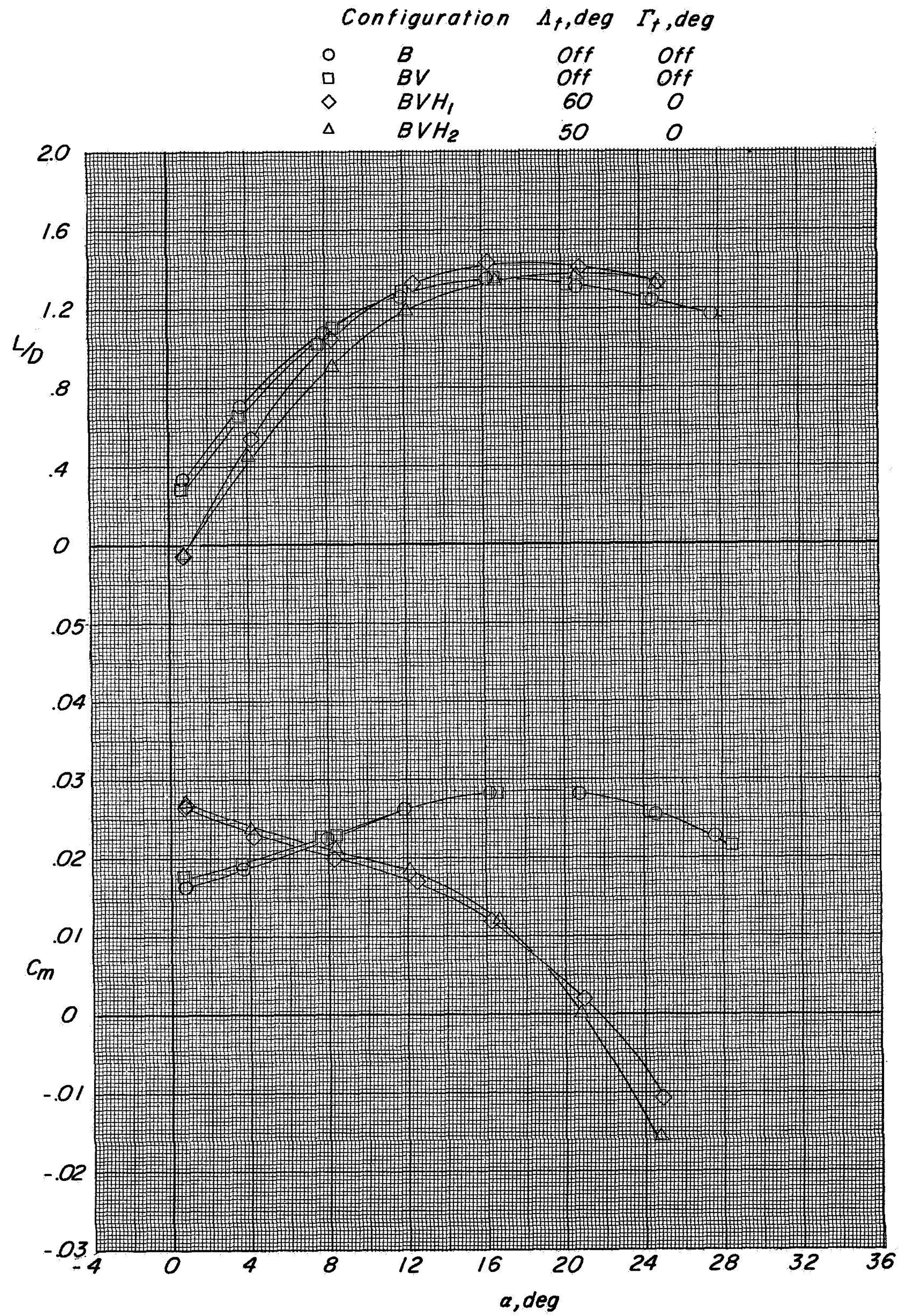


Figure 3.- Continued.



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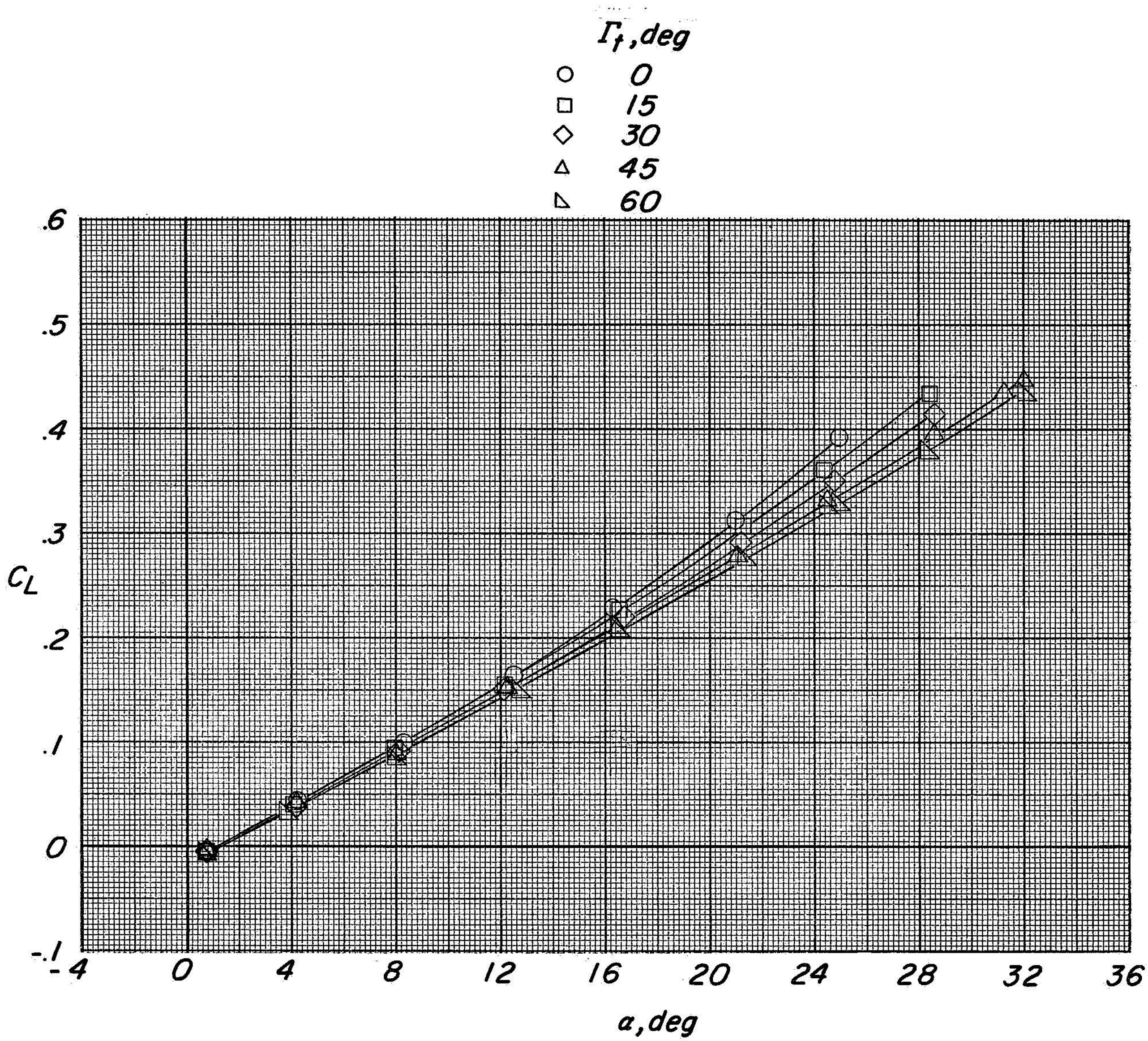
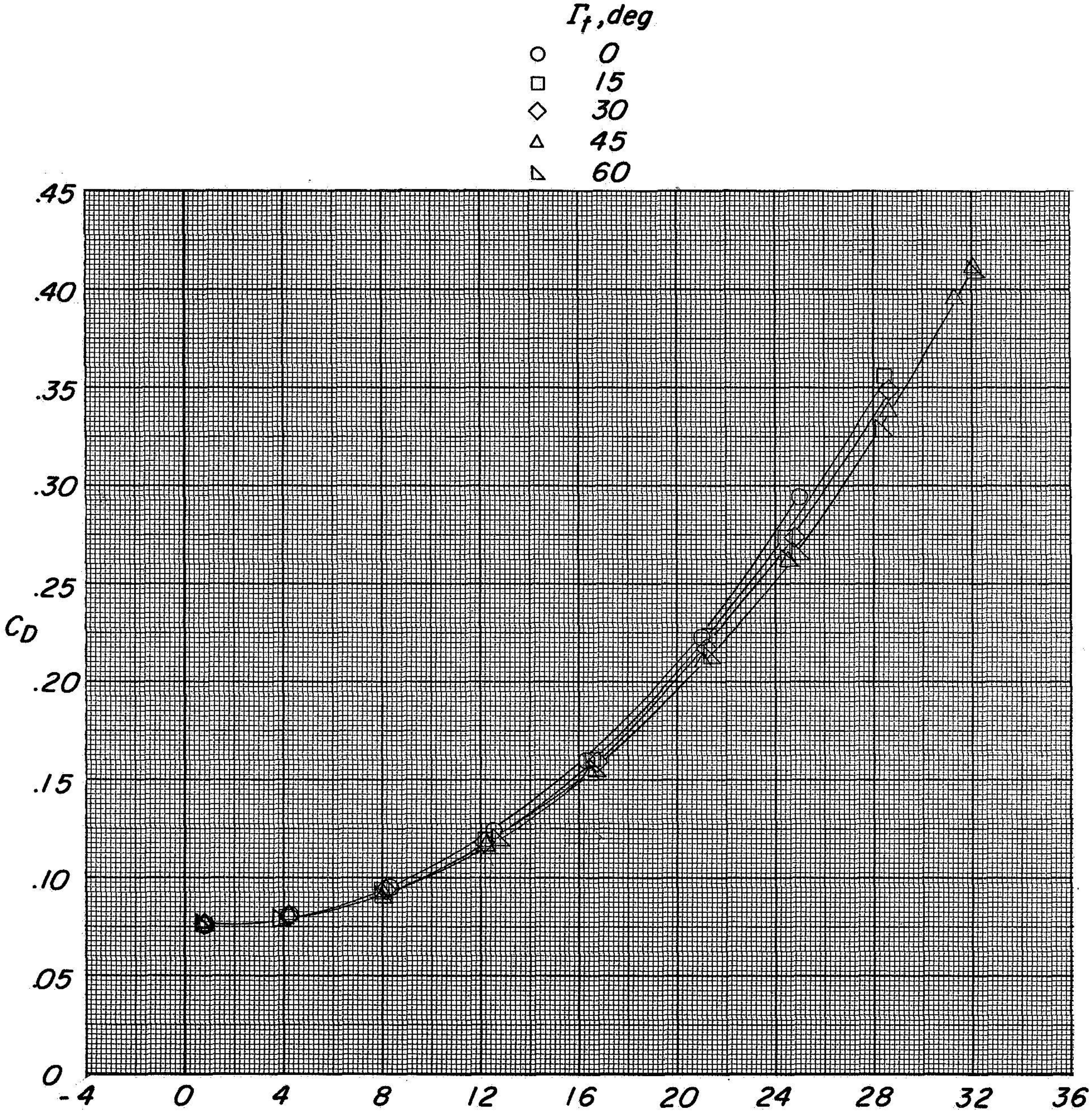


Figure 4.- Effects on longitudinal characteristics of changing dihedral on the horizontal stabilizer with $\Lambda_t = 60^o$. Configuration BH_1V; $\delta_e = 0^o$.



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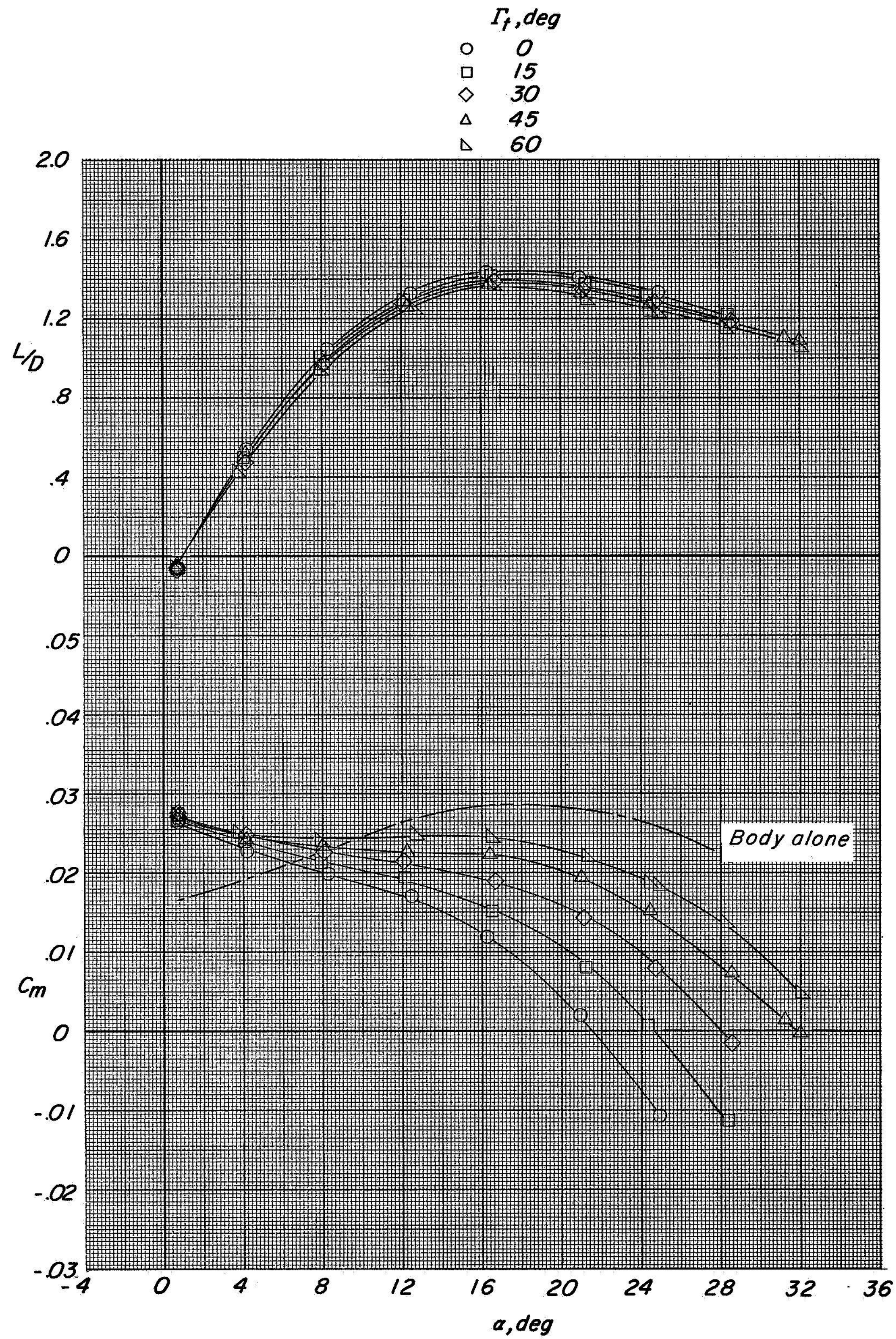

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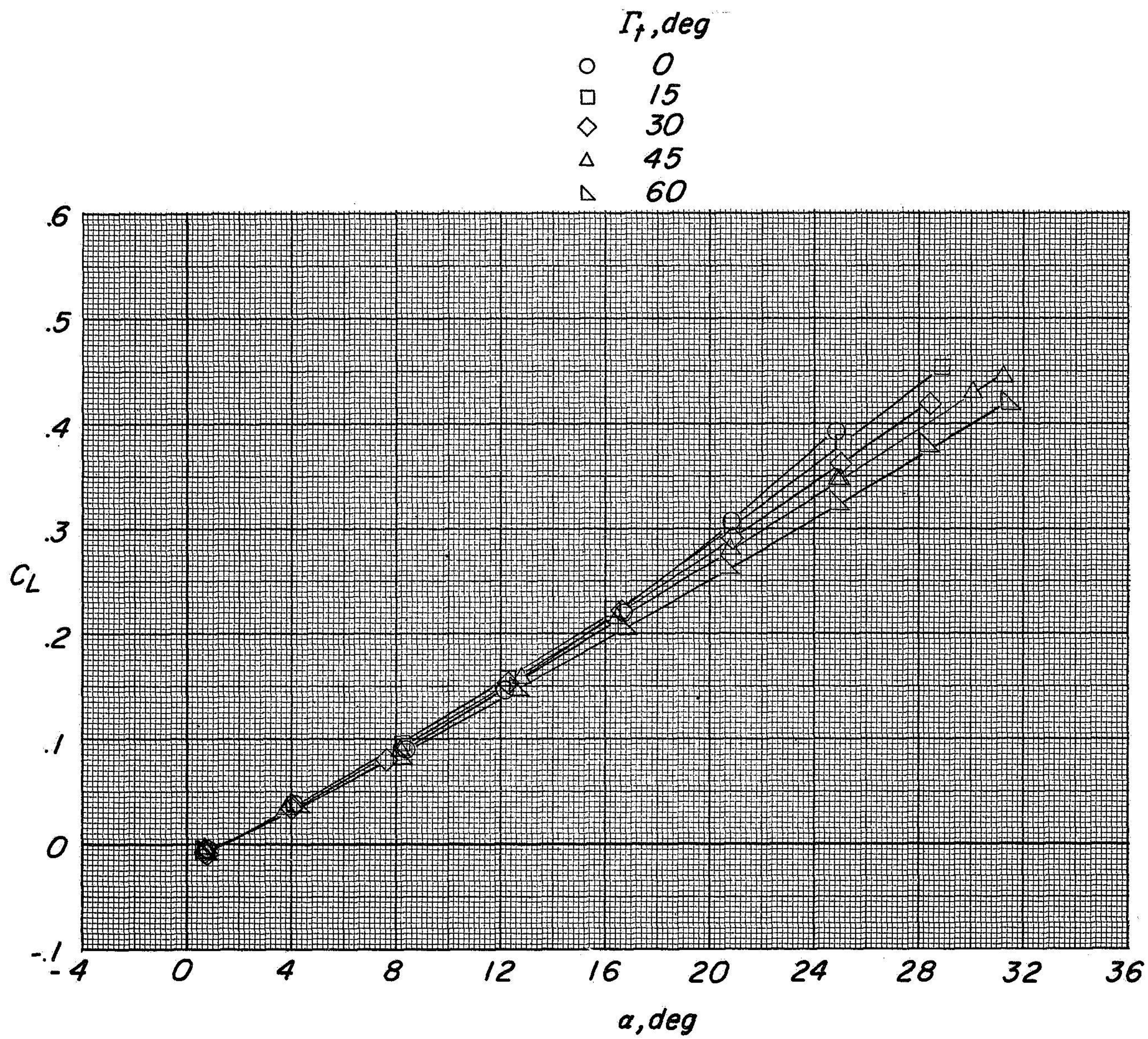
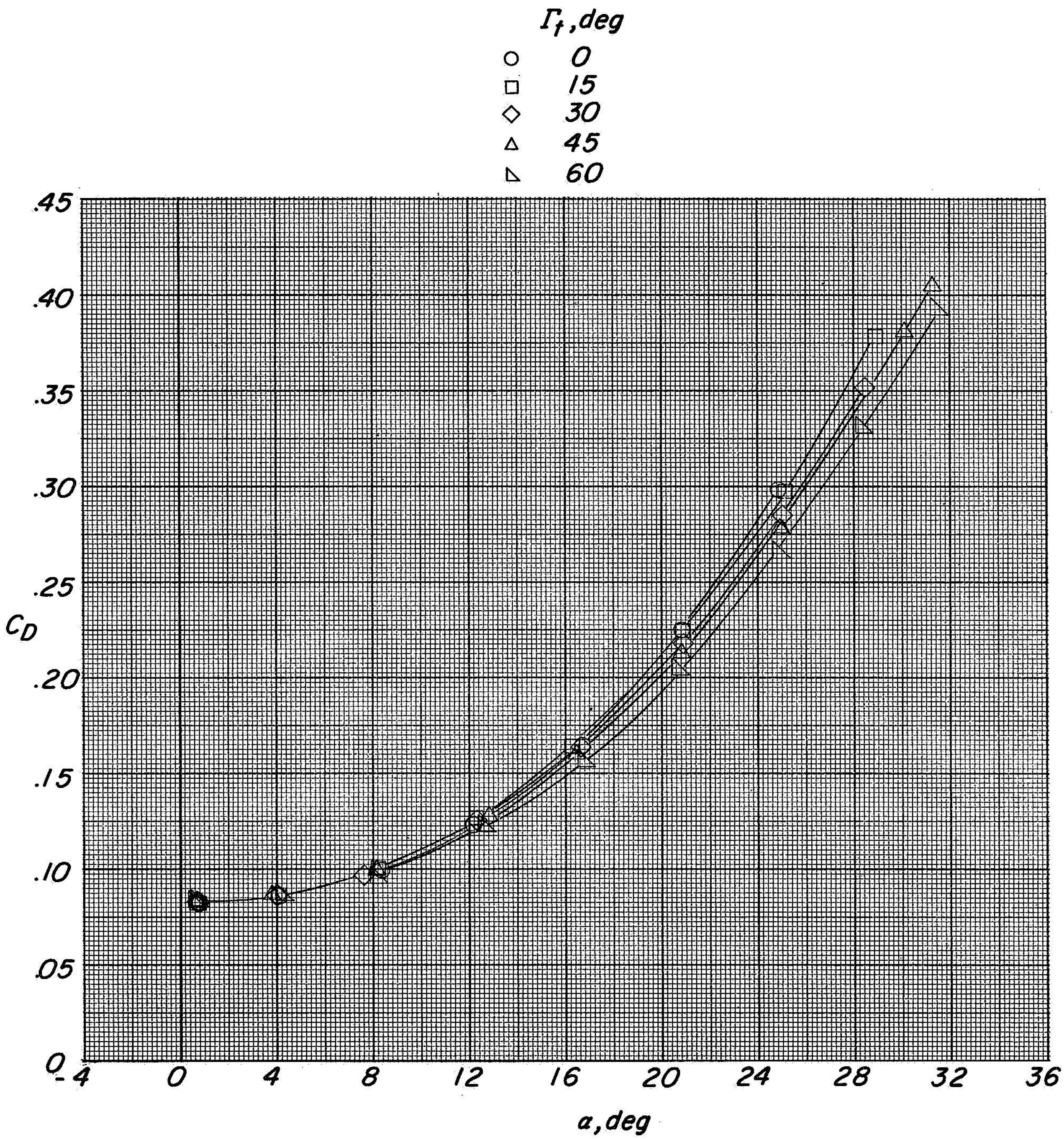


Figure 5.- Effects on longitudinal characteristics of changing dihedral on the horizontal stabilizer with $\Lambda_t = 50^0$. Configuration BH_2V; $\delta_e = 0^0$.



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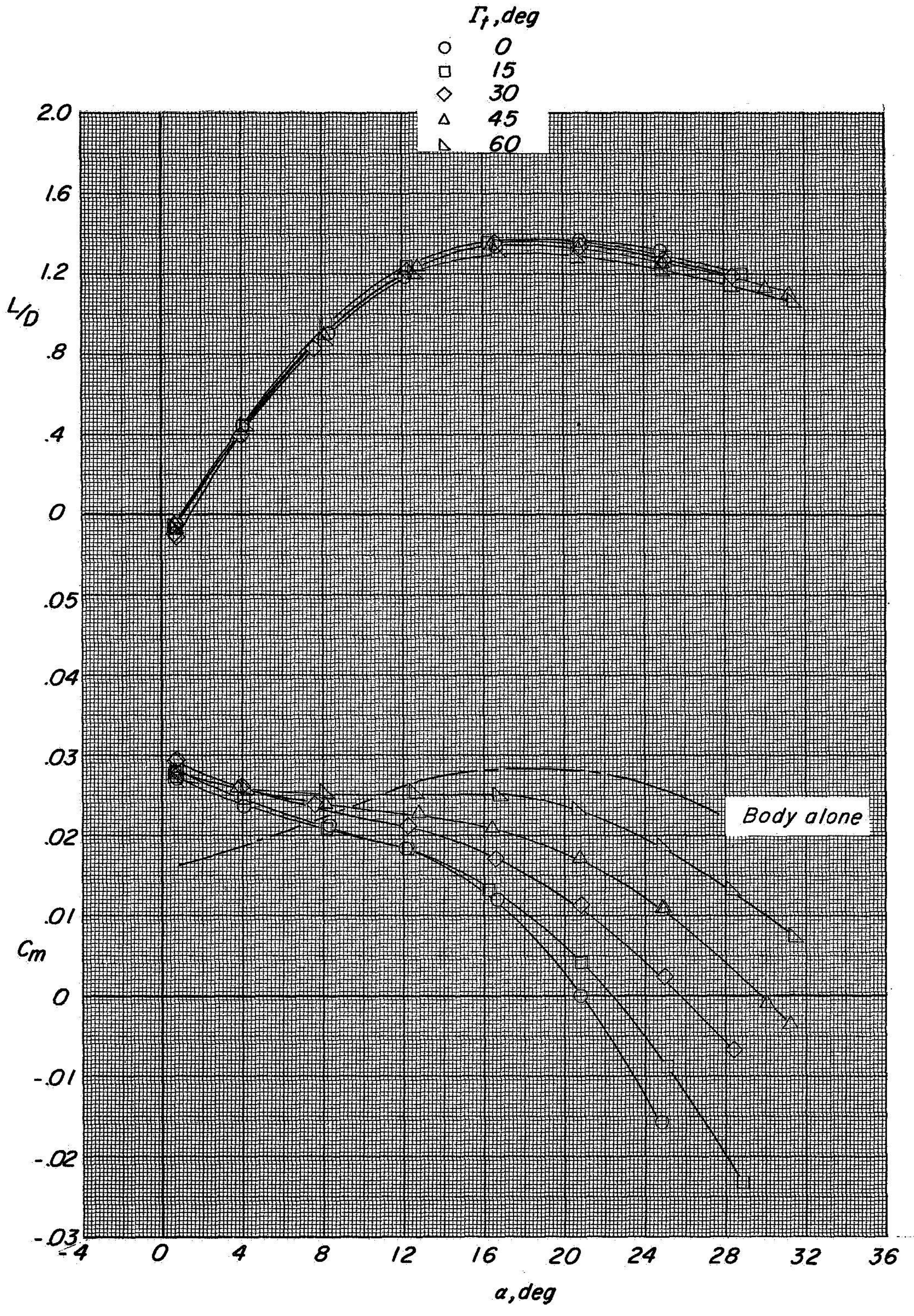

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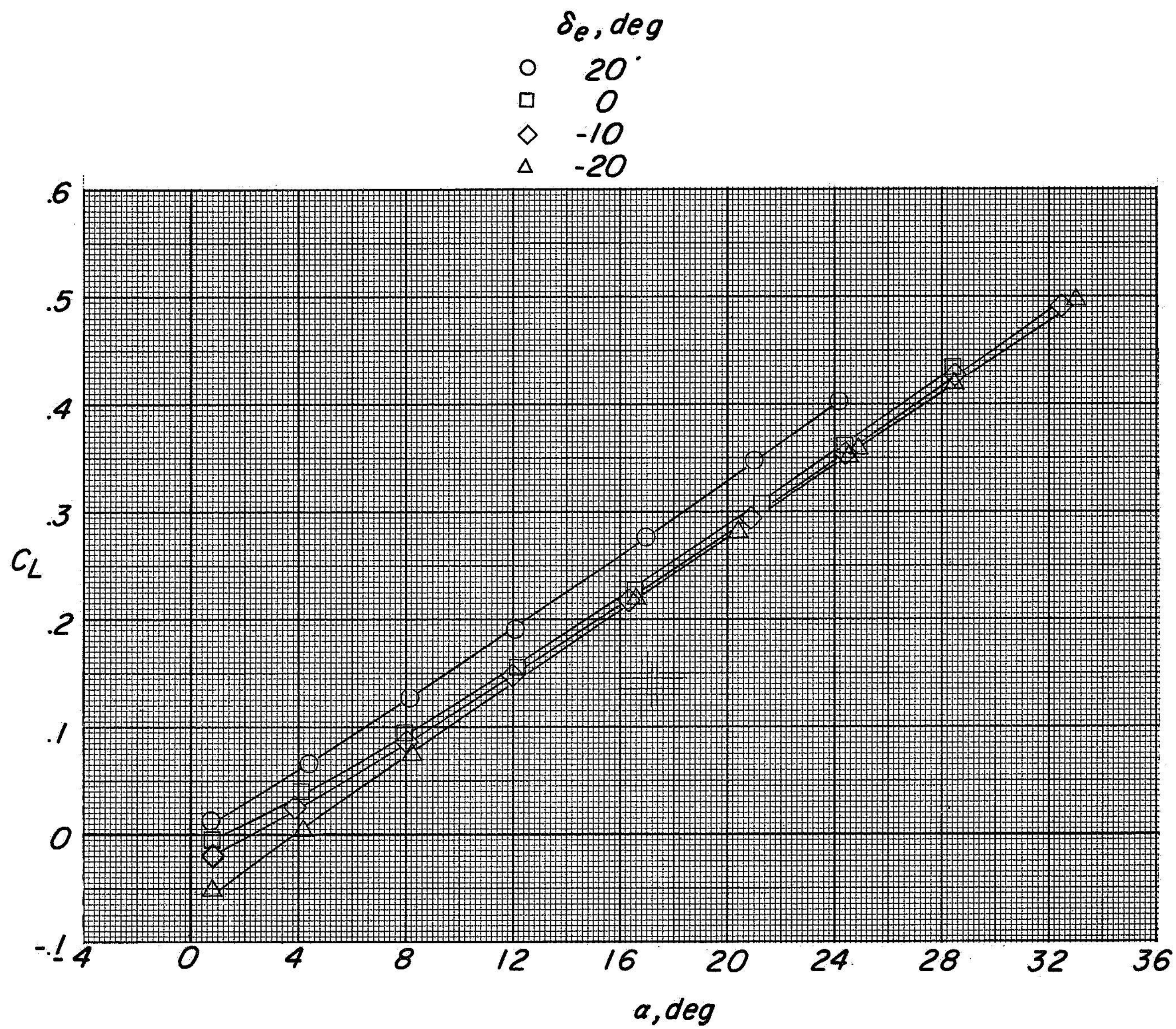
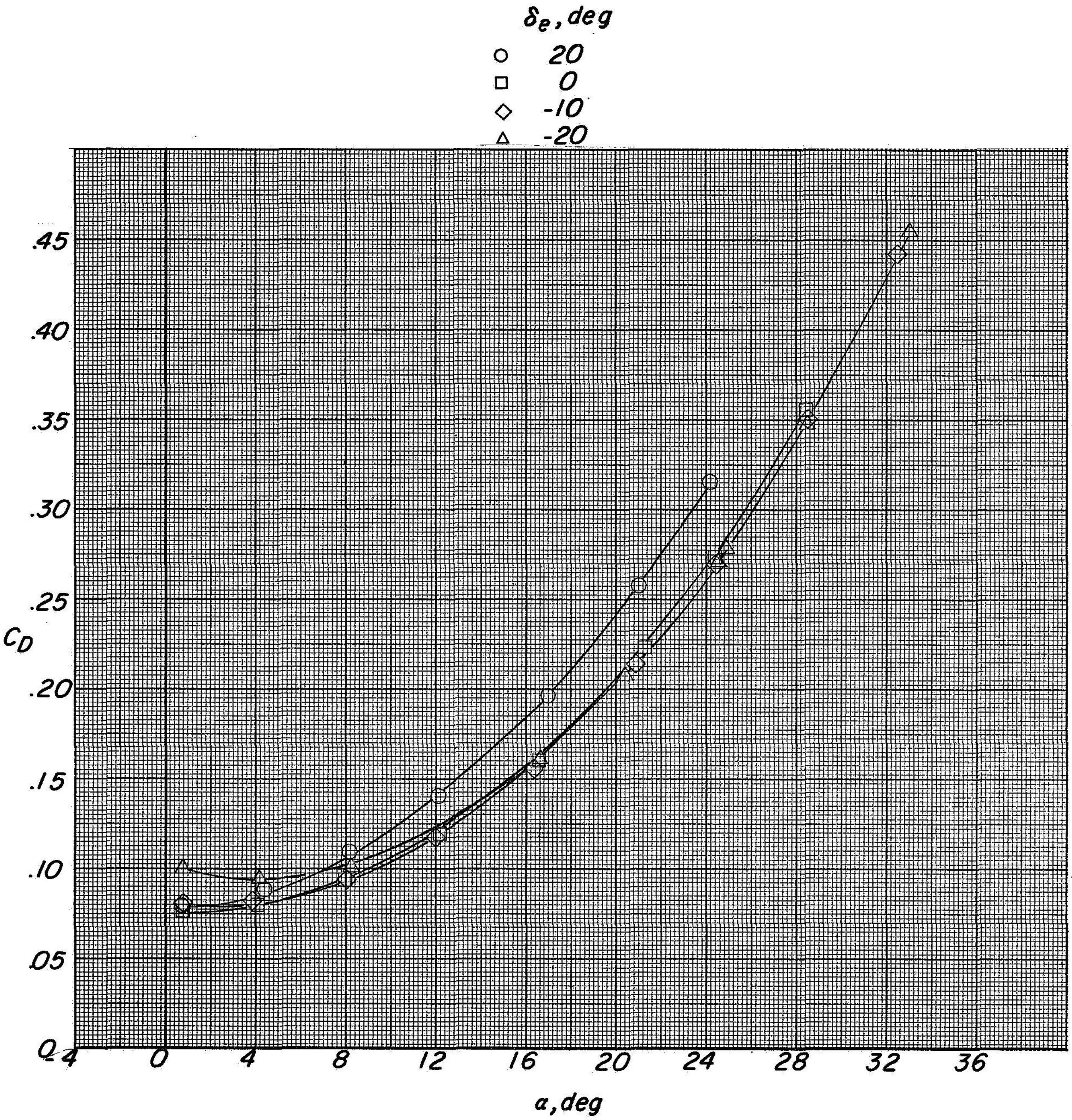


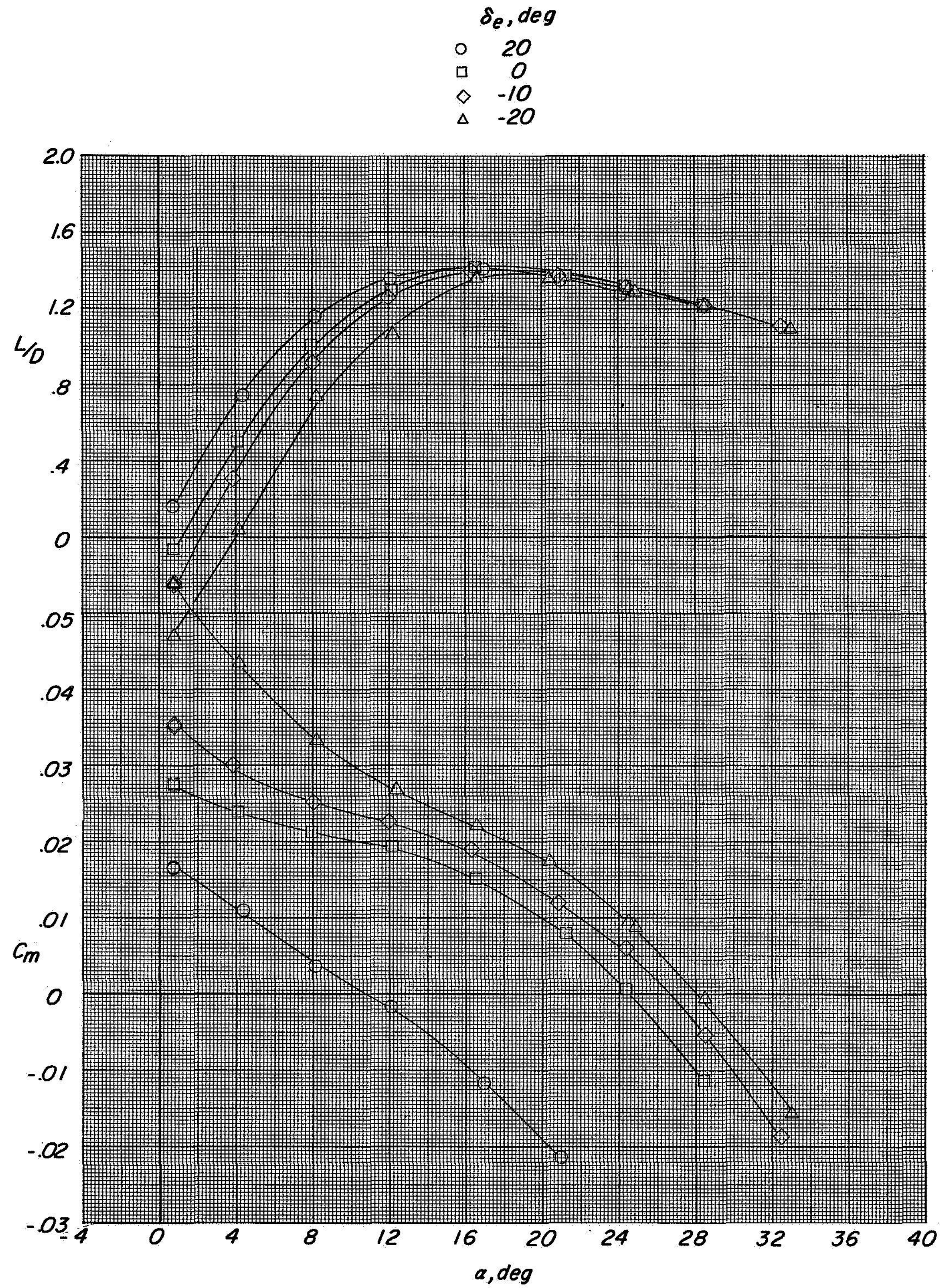
(a) $\Gamma_t = 15^0$.

Figure 6.- Effects of elevon-control deflection on the longitudinal-control characteristics of the horizontal stabilizer with $\Lambda_t = 60^0$. Configuration BH_1V.



(a) Continued.

Figure 6.- Continued.



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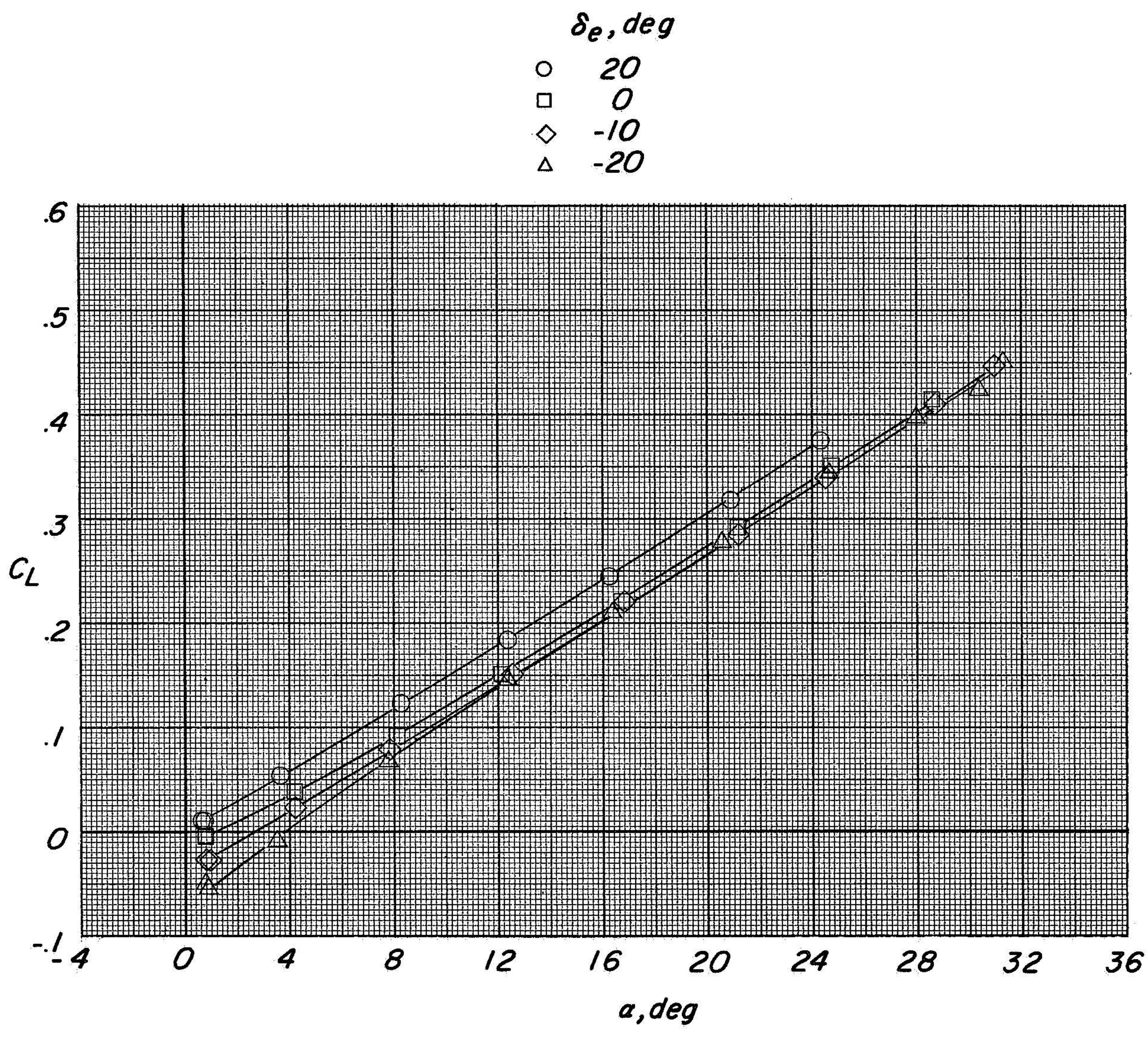

(b) $\Gamma_t = 30^0$.

Figure 6.- Continued.

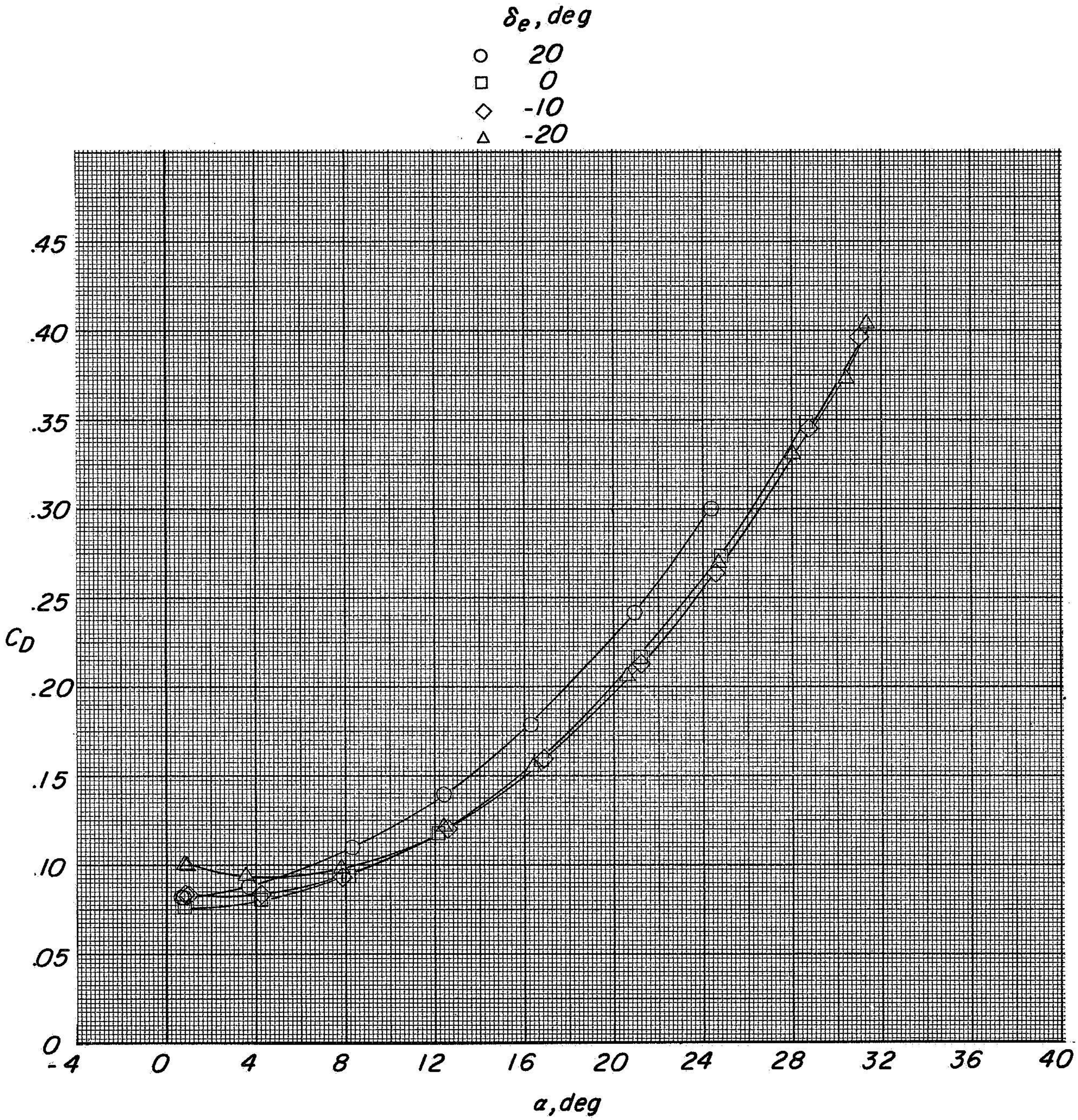

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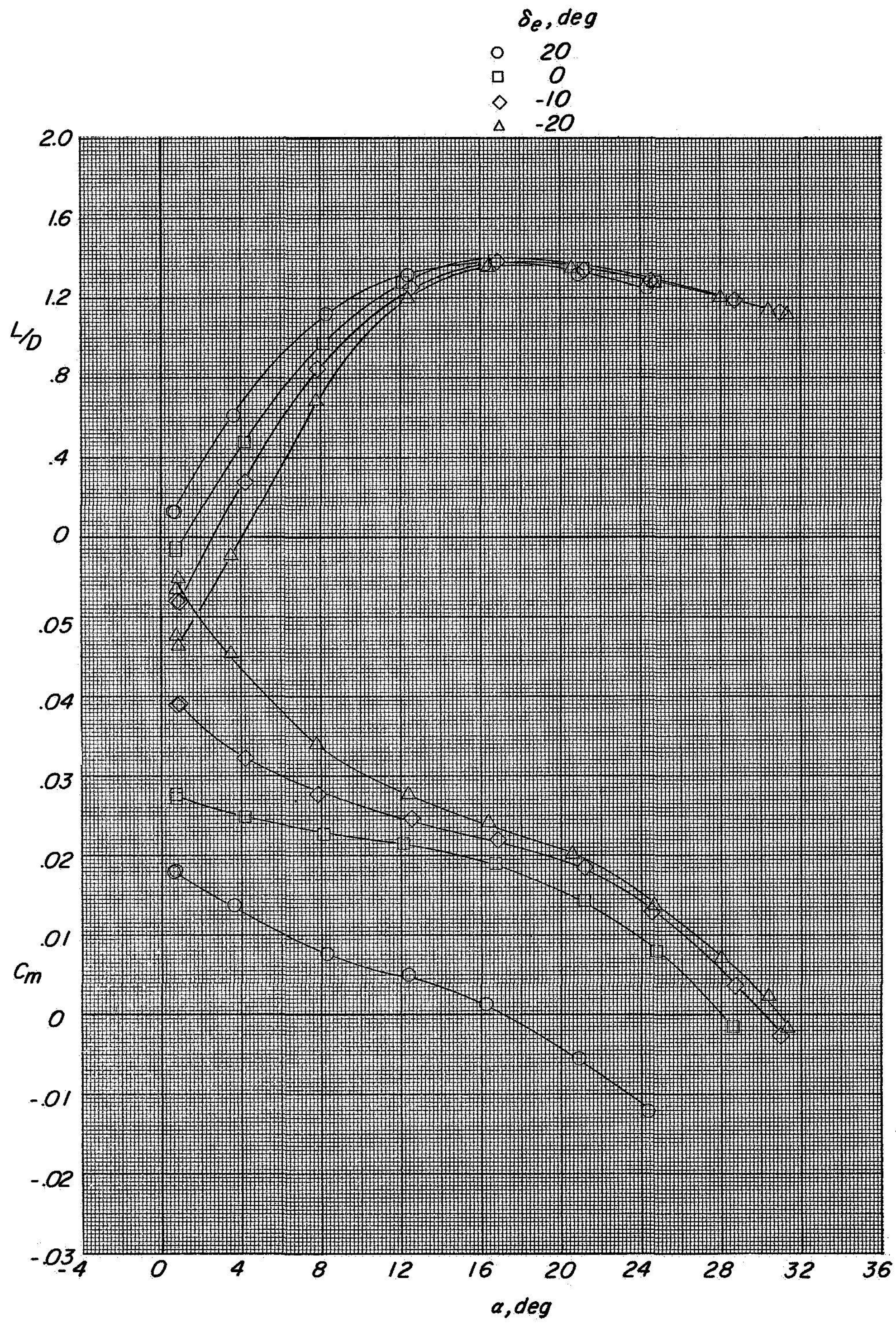
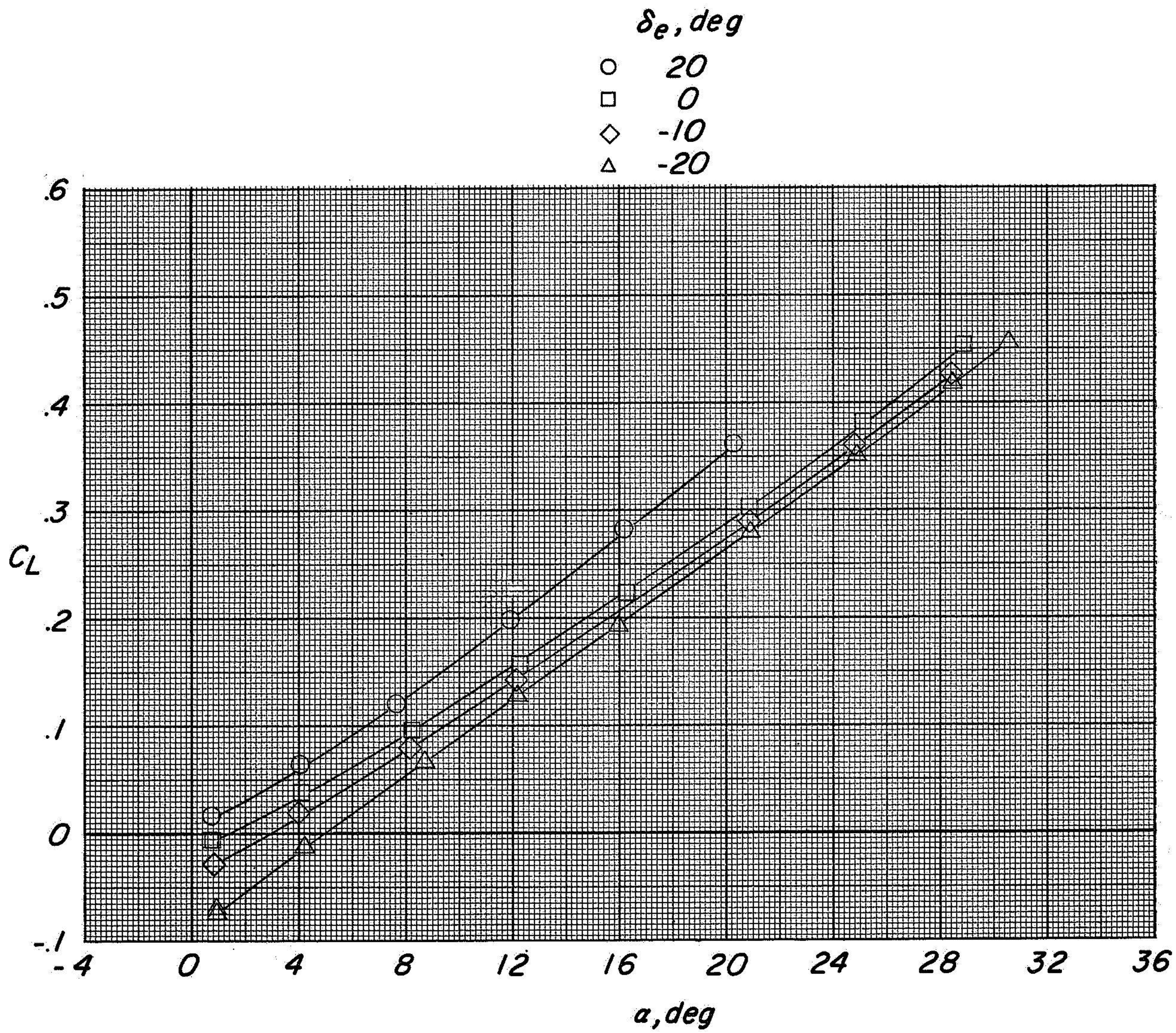
Figure 6.- Continued.



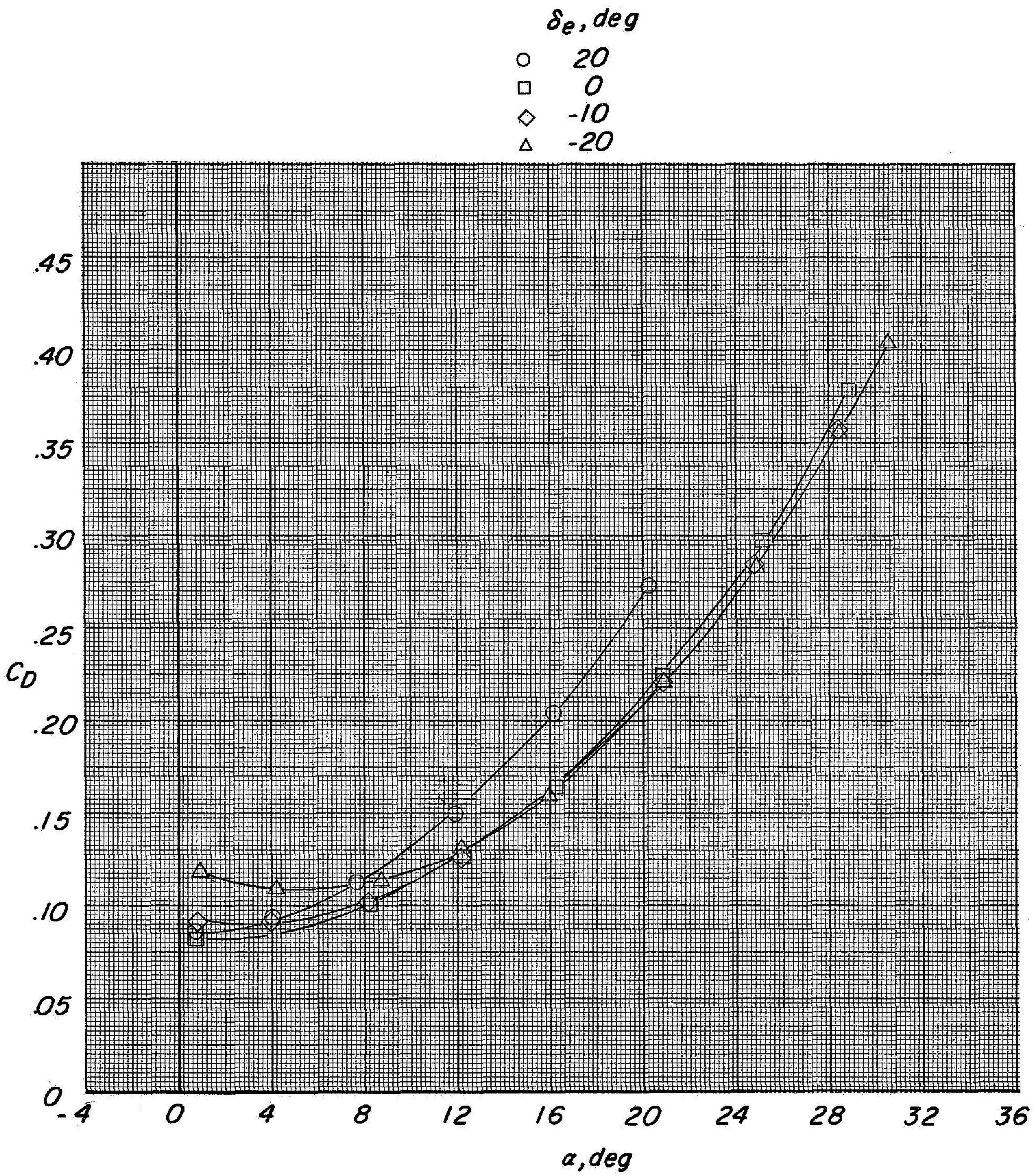
(b) Concluded.

Figure 6.- Concluded.



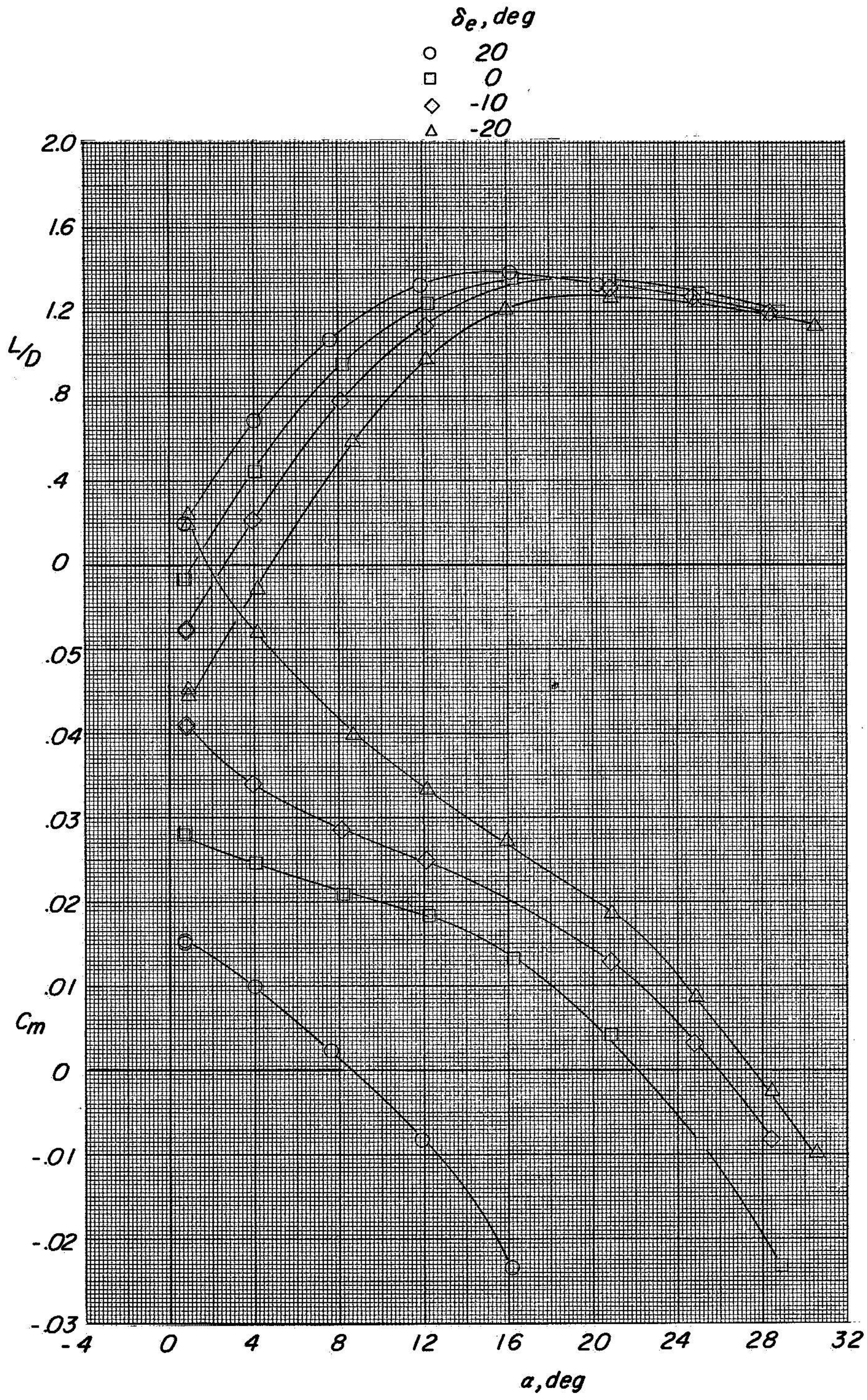
(a) $\Gamma_t = 15^0$.

Figure 7.- Effects of elevon-control deflection on the longitudinal-control characteristics of the horizontal stabilizer with $\Lambda_t = 50^0$. Configuration BH_2V.



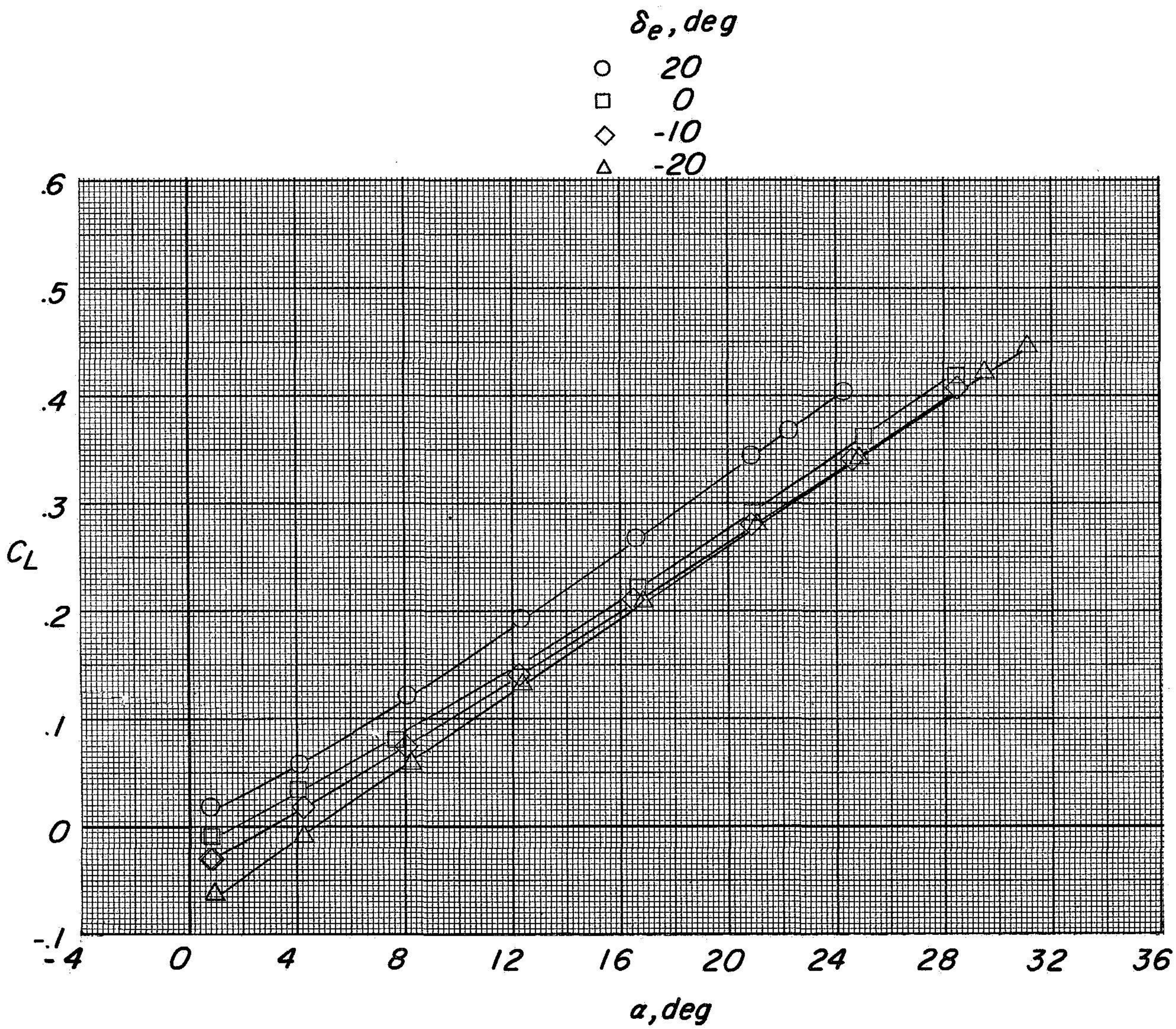
(a) Continued.

Figure 7.- Continued.



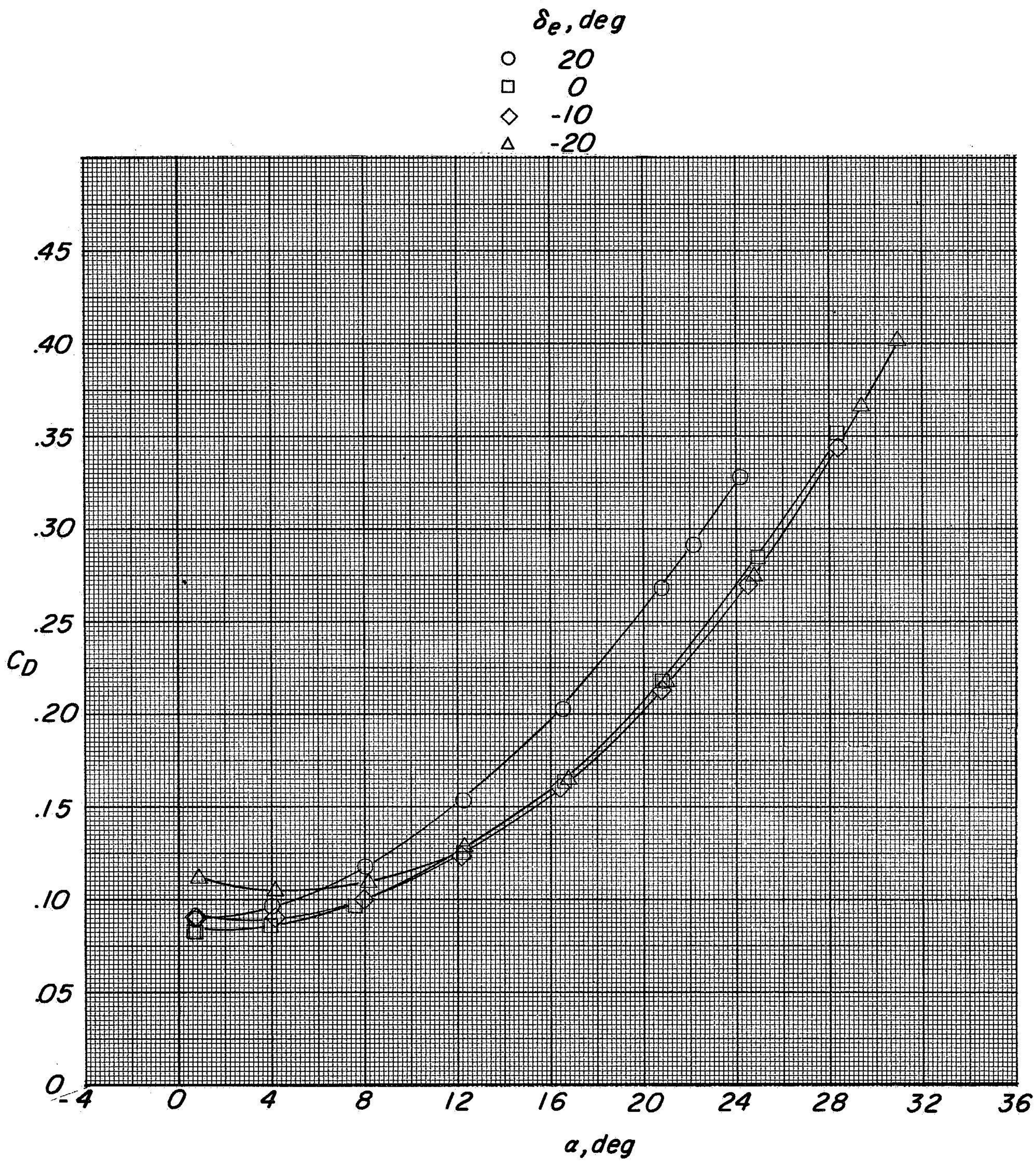
(a) Concluded.

Figure 7.- Continued.



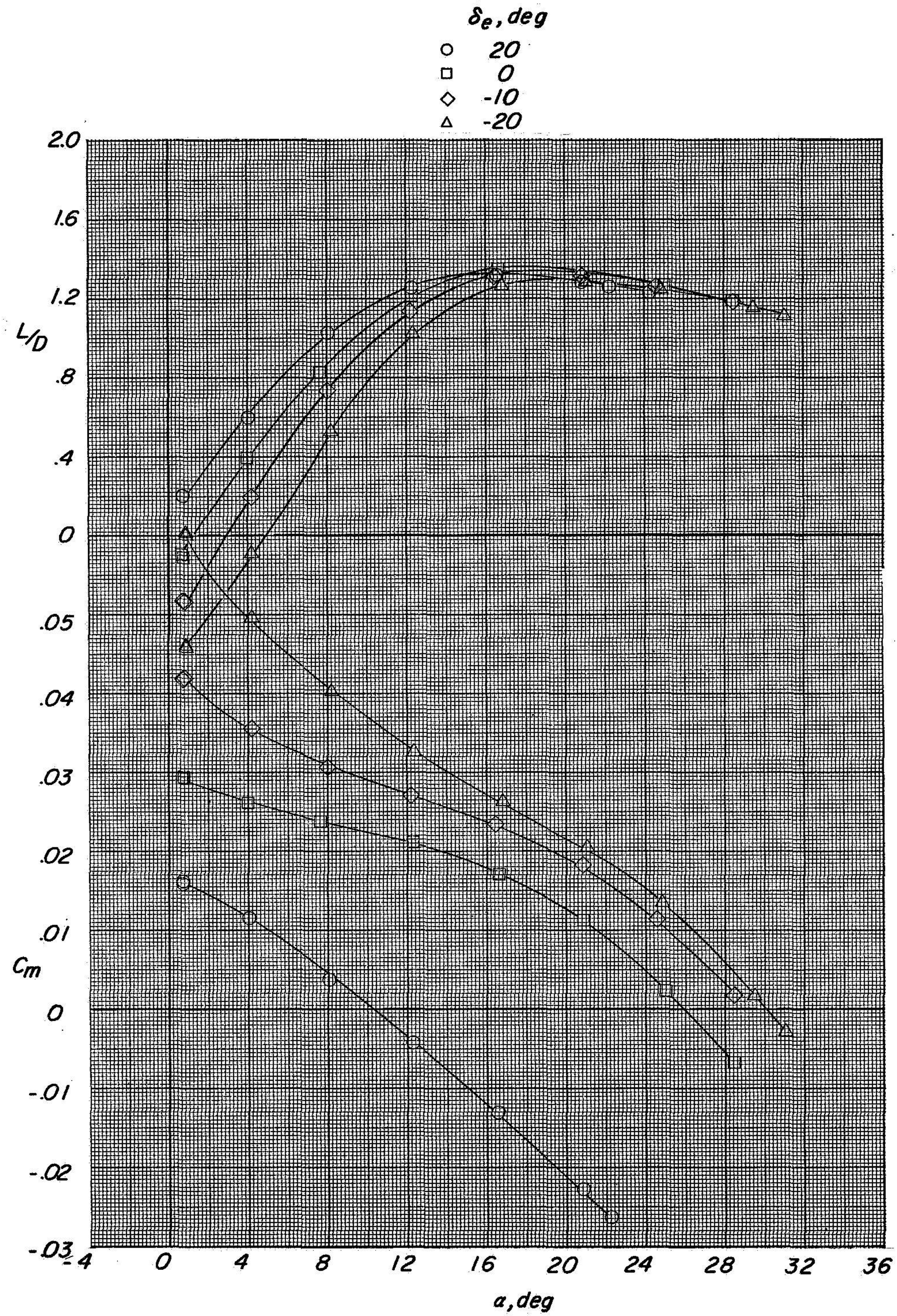
(b) $\Gamma_t = 30^o$.

Figure 7.- Continued.



(b) Continued.

Figure 7.- Continued.



(b) Concluded.

Figure 7.- Concluded.

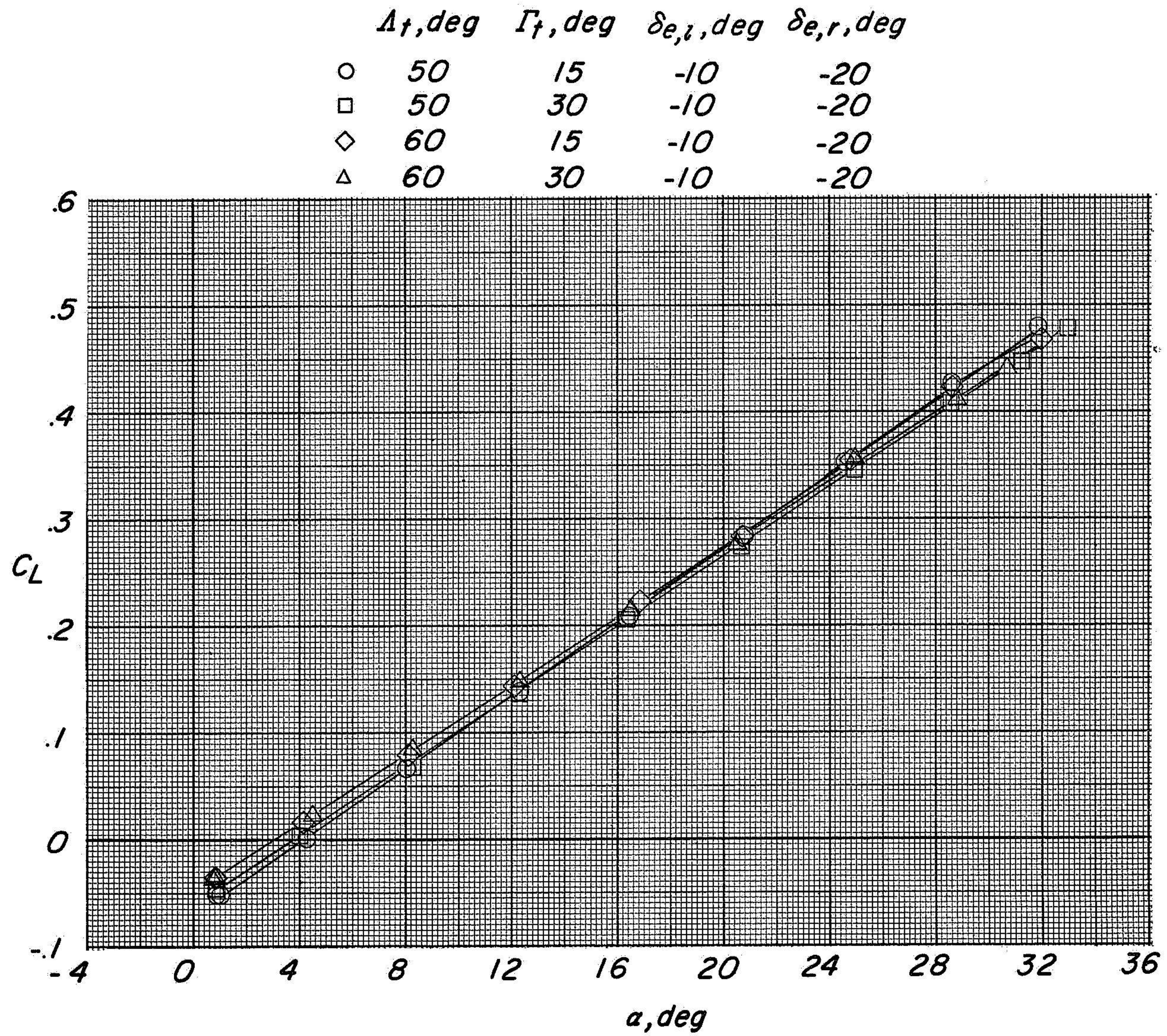


Figure 8.- Effects of differential deflection of elevon controls on the longitudinal- and lateral-directional-control characteristics for horizontal stabilizers H_1 and H_2.

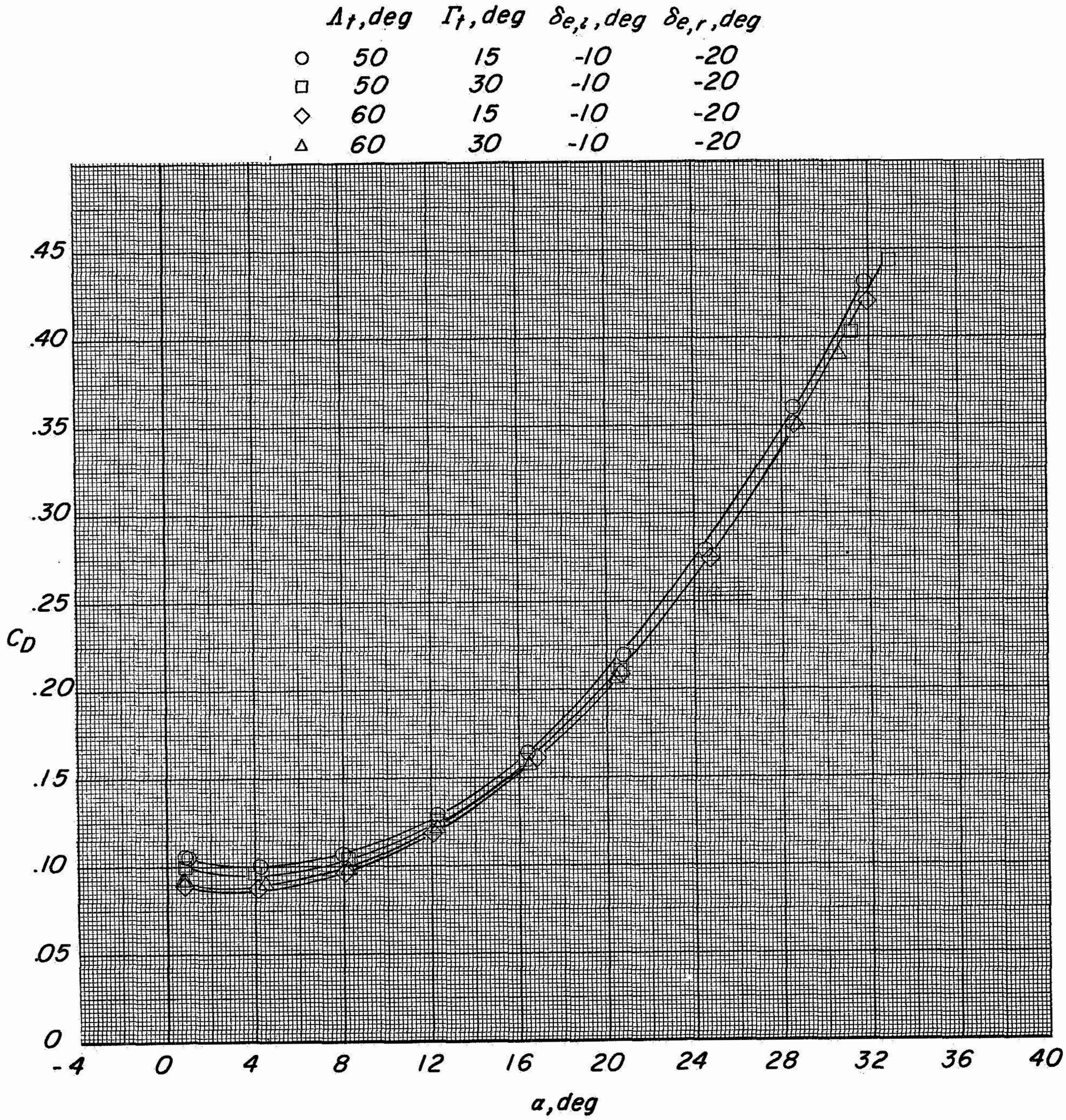


Figure 8.- Continued.

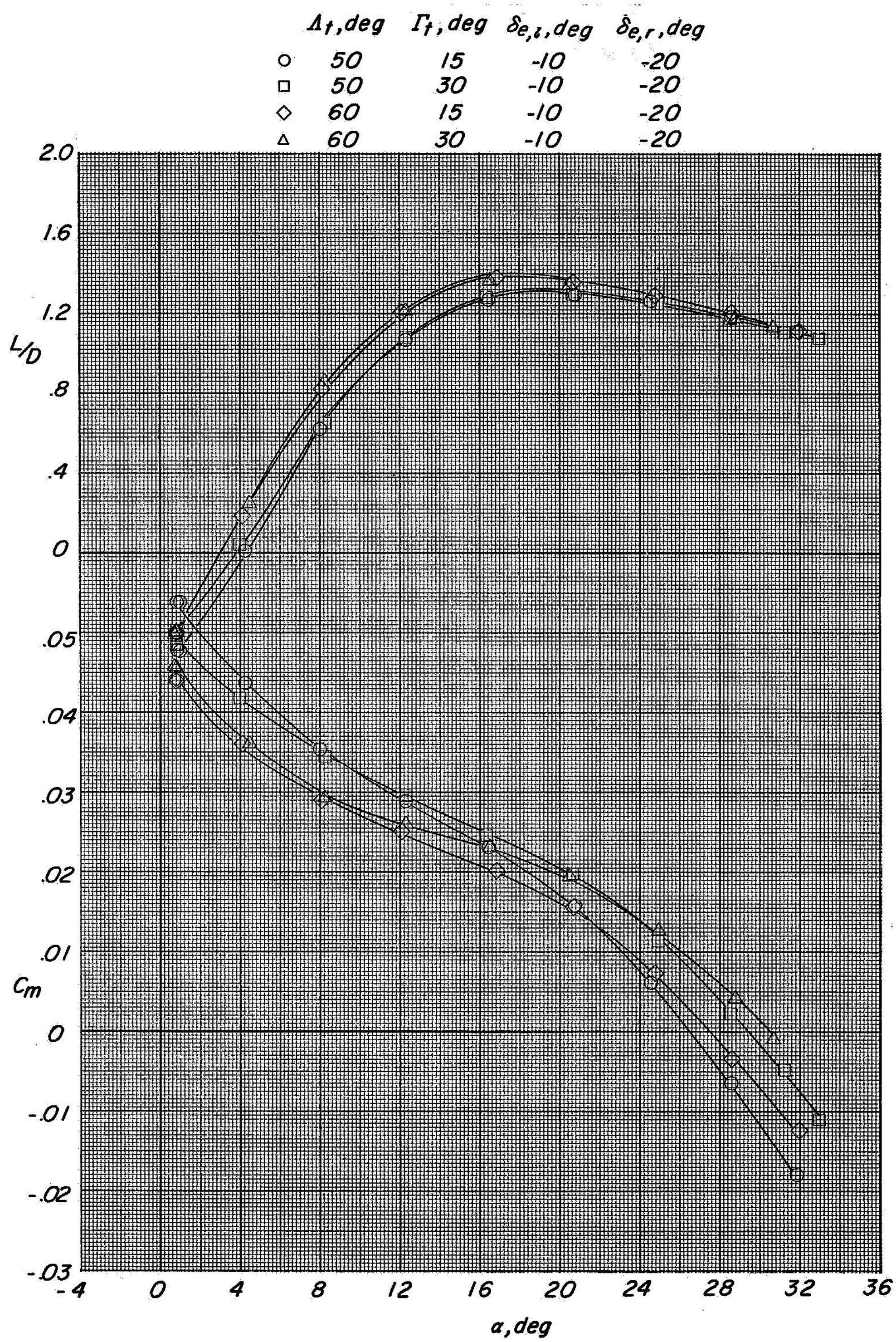


Figure 8.- Continued.

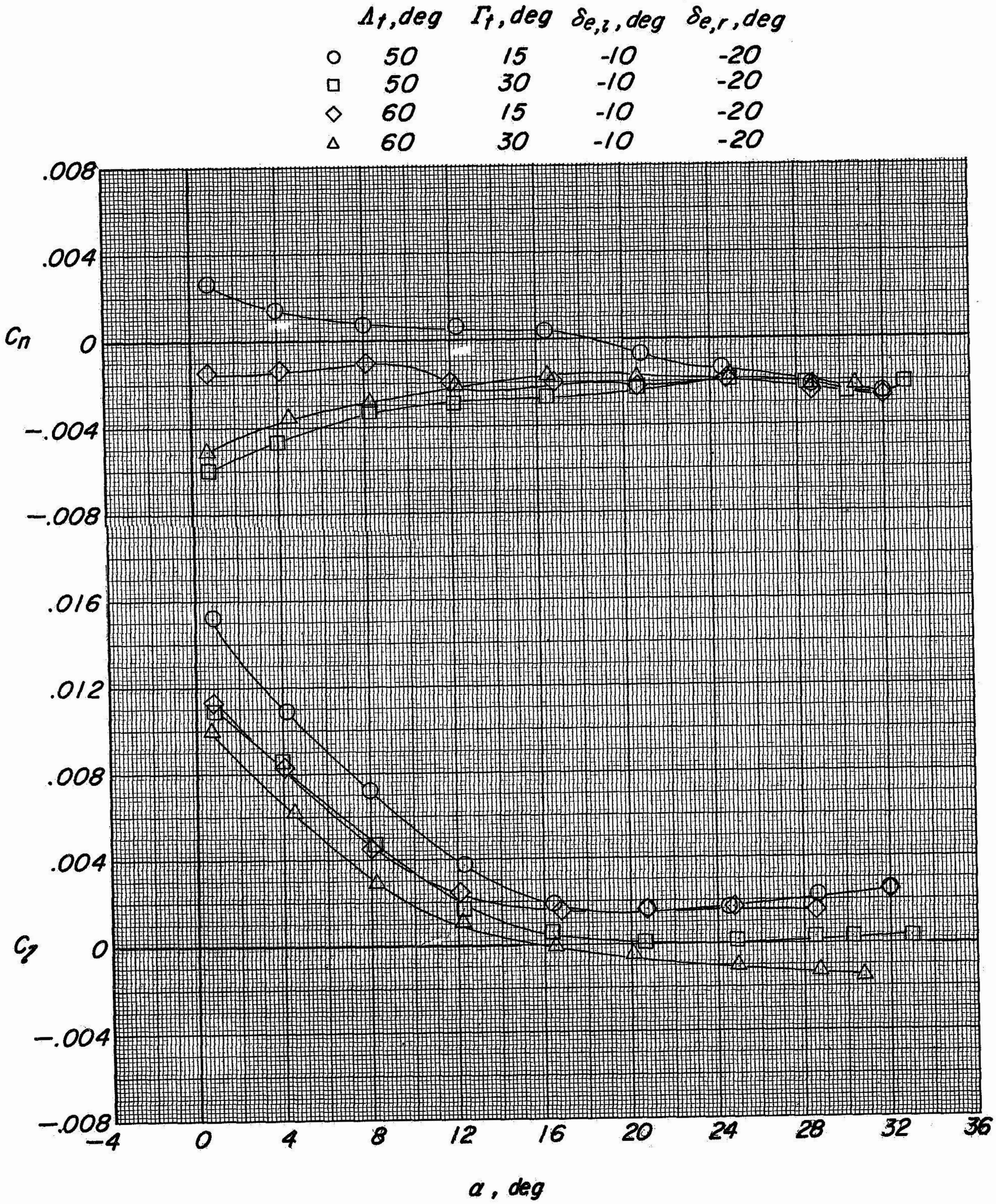


Figure 8.- Concluded.

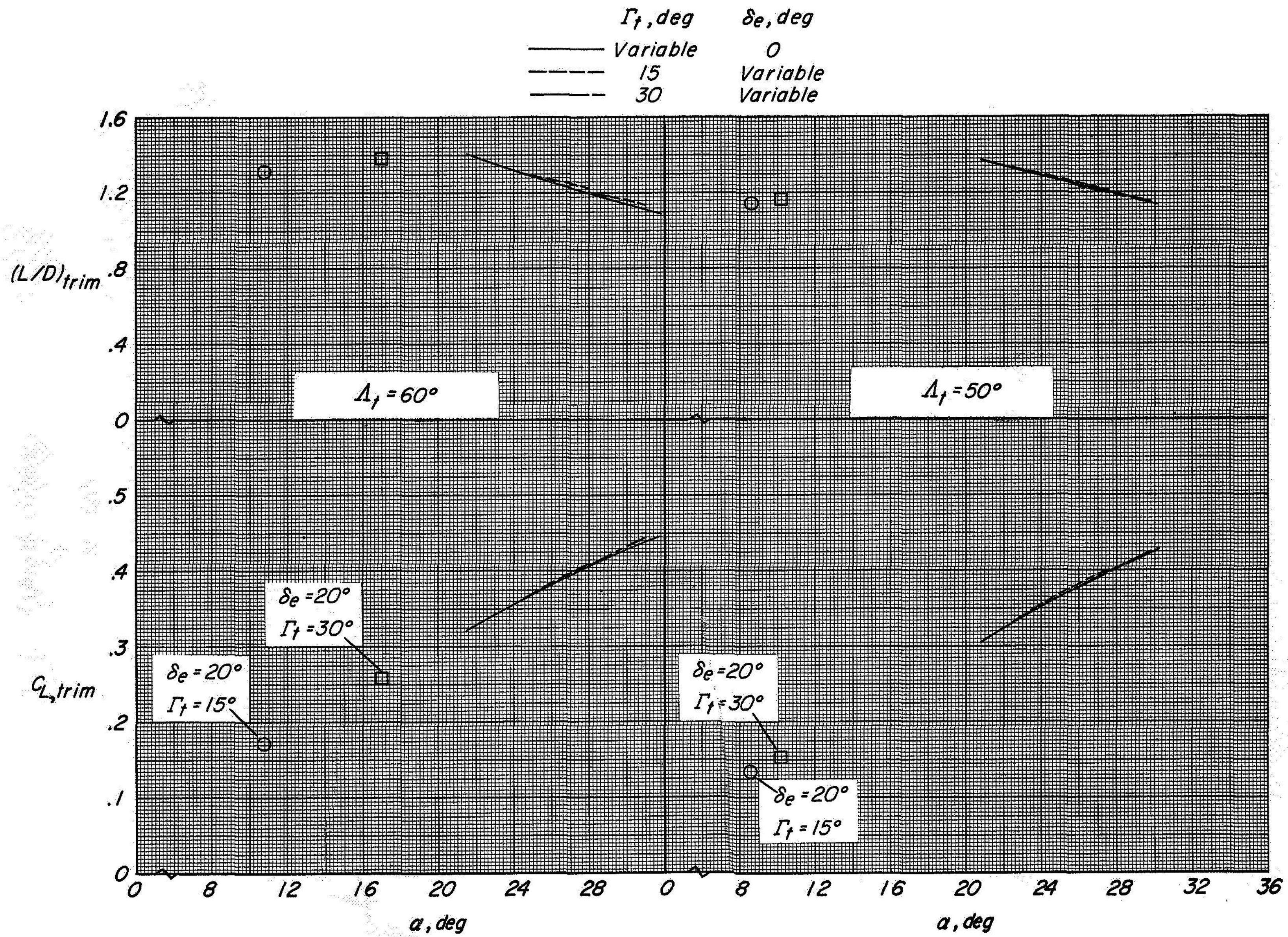
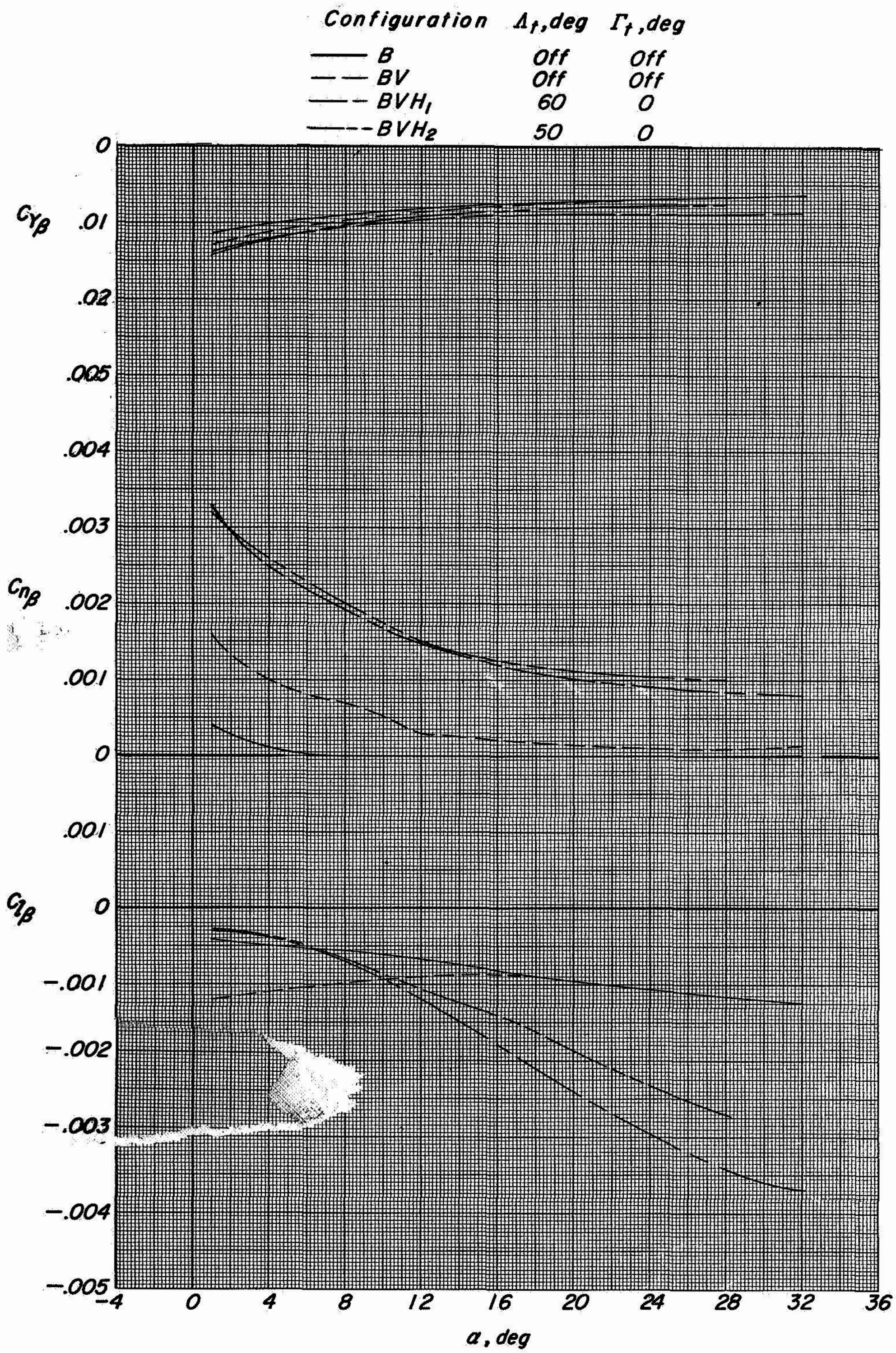
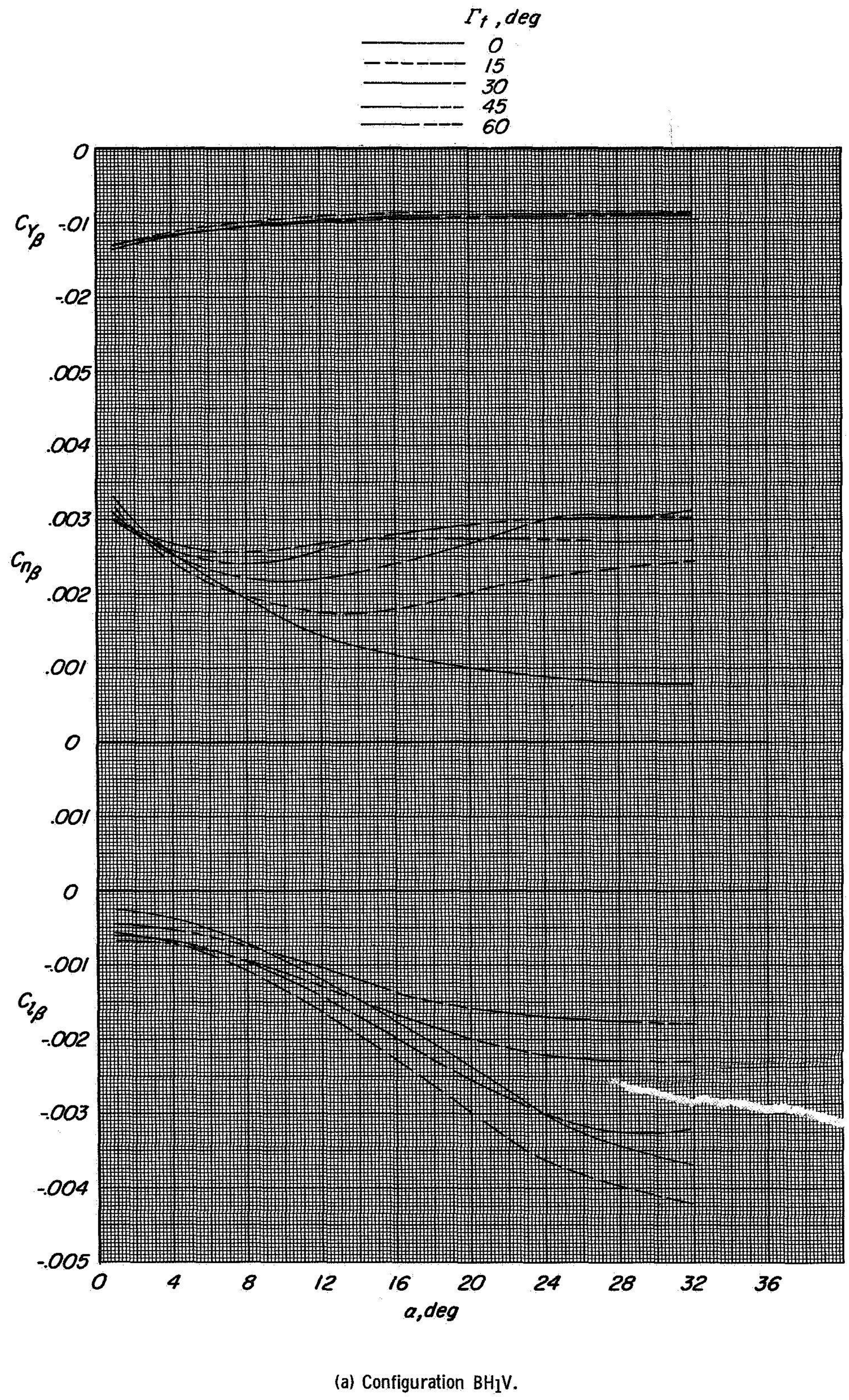


Figure 9.- Summary of trimmed longitudinal characteristics as affected by variable elevon deflection for fixed dihedral or variable dihedral for fixed elevon.

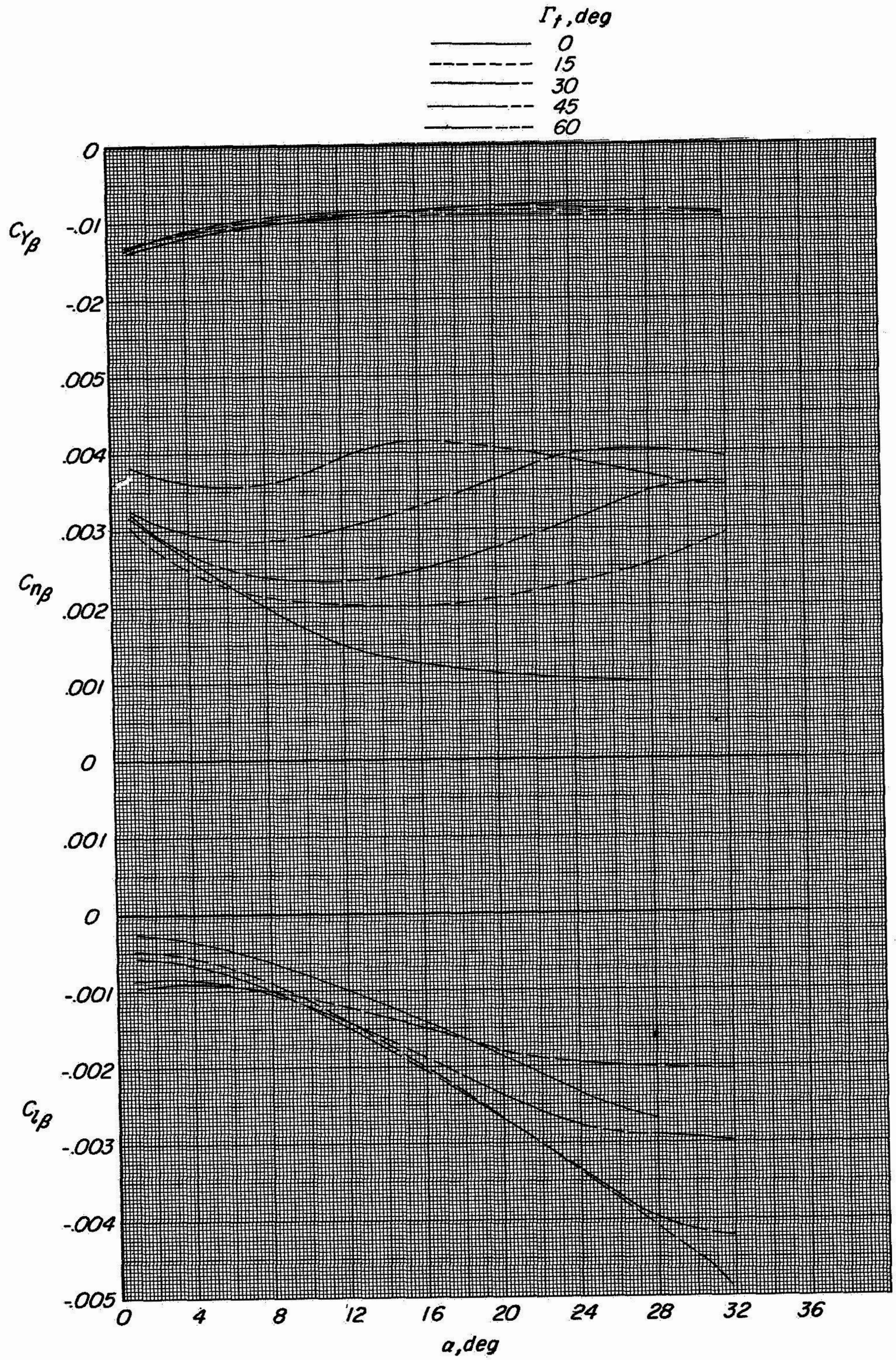


.- Summary of lateral-directional-stability characteristics of the body as affected by addition of vertical and horizontal stabilizers. $\delta_e = 0^0$.



(a) Configuration BH_1V.

Figure 11.- Summary of lateral-directional-stability characteristics as affected by changes in outboard-stabilizer di



(b) Configuration BH_2V.

Figure 11.- Concluded.

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